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**JUMPING TO CONCLUSIONS: THE EFFECTS OF HYDRATION STATUS ON  
KINETICS AND ELECTROMYOGRAPHY IN THE VERTICAL JUMP**

A Dissertation

Presented in partial fulfillment of requirements

for a degree of Doctor of Philosophy

in the Department of Health, Exercise Science

and Recreation Management

The University of Mississippi

By

**Paul T. Donahue**

**May 2018**

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## ABSTRACT

**Background:** The countermovement (CMJ) and squat jumps (SJ) are two of the most popular assessments used of lower body power output in athletic populations. One potential variable that could impact performance of these tasks is the hydration status of the athlete. Current literature is fairly consistent in that the majority of athletes arrive at competition and training sessions in a hypohydrated state. While the effects of hypohydration on aerobic performance are well known, there is inconsistency in the literature regarding its effects on anaerobic performance and the mechanism to any reduction. Thus, the purpose of this investigation was to examine the effects of hydration status on vertical jump performance while concurrently examining the proposed mechanism to any reduction. Additionally, comparisons were made between jumping techniques to examine possible mechanisms to performance differences.

**Methods:** 25 trained males between the ages of 18 – 35 participated in the investigation. A counterbalanced crossover design was used. Participants performed three CMJ and SJ in each of the three hydration conditions. Sessions were separated by 24 hours. Additionally, during the jumping task mean muscle activity was collected using EMG. A repeated measure ANOVA was used to assess difference in jump performance and muscle activity. Paired sample t-test were used to assess differences between CMJ and SJ.

**Results:** Significant differences were present between hypo- and euhydrated conditions for peak and mean force during the CMJ with no difference in jump height. Significant differences were

present between conditions for jump height and jump velocity for the SJ. No differences were seen in any of the four muscles of interest in regard to muscle activation. Significant differences were present between jump height of the CMJ and SJ respectively, with high correlation coefficients to jump velocity in both jump techniques.

**Conclusions:** The countermovement itself during the CMJ seems to provide an attenuation to any effects hypohydration, as the SJ has significantly lower values during hypohydration as compared to euhydration. As for the mechanism for this reduction to occur it appears that changes outside the neuromuscular system may be responsible as no differences were seen in muscle activation both during MVC and the jumping task itself. Differences between jumping technique appear to be driven by the movement velocity itself as levels of force and power were either not different or higher in the SJ while CMJ achieved a greater outcome as assessed through jump height.

## **ACKNOWLEDGEMENTS**

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**CHAPTER I**  
**INTRODUCTION**

As long as athletic competitions have existed, both athletes and those involved in athletics (sport coaches, athletic trainers, strength and conditioning coaches, etc.) have attempted to improve performance. Whether this has been through the different training modalities, injury prevention strategies, the use of performance-enhancing drugs or methods to enhance recovery and reduce fatigue those involved in competition have always strived to improve subsequent performance and compete at the highest possible level. As athletes strive to improve and achieve their optimal performance, modifications are made to the training loads required to have optimal performance. These training loads are not always in the context of loads lifted during resistance training sessions, but in the total training (resistance and sprint training, technical and tactical training, aerobic conditioning) that in athlete goes through to improve performance. The training loads are varied throughout the training cycle depending on the phase of training that an athlete is currently in (offseason, preseason, competition, post season). The management of fatigue is an important part to the both adaptations to training as well as performance in competition (76,135,137).

Fatigue is a complex and multidimensional occurrence that has a wide array of possible mechanisms and is often difficult to define (51,76,133). One of the most common definitions for muscle fatigue is a “failure to maintain the required or expected force” proposed by Edwards (51). With increases in training and competition loads due to increases in the frequency of competitions and the additional length to competitive seasons the importance of managing fatigue in athletes has become critical to achieving and maintaining a high level of performance.

Many laboratory methods that investigate neuromuscular fatigue are performed in isolated muscle groups and in isometric conditions. As these methods, allow researchers to study the mechanisms that cause fatigue, it becomes difficult to translate to the dynamic explosive nature of movements seen during athletic performance. Thus, the increase in the use of maximal-performance assessments including sprints, repeated-sprints, jumping variations have been used to make an effort to quantify the rate at which recovery is occurring in the subsequent hours and days after training and competition (135). A key factor in the establishment of a fatigue monitoring protocol in athletic settings is the simplistic nature and the lack of fatigue that is produced during the protocol itself. Two of the most popular tests to measure training load and fatigue in athletic populations are the countermovement and squat jumps (133). These are commonly performed at the beginning of a training session and take minimal amount of time to complete. It has been suggested by some that the use of jump height as simple measure to indicate early overreaching (143,146), while others have suggested that jump height lacks the sensitivity needed to detect changes that would show signs of neuromuscular fatigue (24,38). This has led to the use of both kinetic and kinematic variables are used in the when assessing jumping performance (38,39,76,96,105).

Jump testing has also become important in determining future training, as it also can be used to assess the readiness that an athlete enters training and competition (35,144). A factor that has not been widely considered in the literature in terms of neuromuscular performance is the hydration status of the athlete. The effects of hydration status on aerobic performance are relatively well known in that when in a hypohydrated state performance is decreased (109). The effects of hydration status on anaerobic physical activity seem to be less clear. The suggested

reasoning for this is the lack of methodological consistency between investigations (85). When examining the effects of hydration status on measures of muscular power (vertical jump) there is conflict in the literature as to the extent of decrement.

As the vertical jump is performed against the resistance of one's own body mass, a reduction in body mass, as seen in much of literature should improve vertical jump performance as long as strength or power is maintained (32). Typically, in investigations involving hydration status there is a decrease in the mass of the subjects (32,85) yet there seems to be little to no impact on vertical jump performance in terms of jump height (71,77,79,85). This is an interesting finding as it has appeared that muscular strength (force output) is impacted by hypohydration (31,85,123). One study found that when using more sophisticated equipment (force platform) rather than jump height alone, hypohydration negatively impacted jumping performance from a biomechanical perspective (vertical ground reaction impulse), this was done with maintaining a constant weight while allowing the subjects to become hypohydrated (32). This investigation additionally showed a reduction in jump velocity and jump height when mass was held constant in a hypohydrated state.

A proposed mechanism for the decrement in performance is from a reduction in neuromuscular function (32,85). The small amount of literature that has investigated the neuromuscular function of hydration state is inconclusive and limited (54,77,85,86). An investigation into the central activation ratio showed that a trend existed between increased levels of hypohydration and a decrease in central activation ratio (86). Electromyography studies investigating hydration state differences show that there is no difference between hypohydrated

and euhydrated conditions (54,77) during isometric and isotonic conditions. These isolated muscle contractions however may be different from those seen in ballistic movements such as the vertical jump. This is an important investigation in that athletic populations typically do not see body mass reductions to produce hypohydrated states. Athletic populations have been shown to enter competition and training session in hypohydrated states (119,120,127,141).

Therefore, the purpose of this study is to investigate the impact of hydration status on the kinetic variables associated with countermovement and squat jump performance. Additionally, this study will investigate the electromyography differences in both hydration states and jumping strategies.

### Hypotheses

The hypotheses for this study are as follows:

H<sub>01</sub>: The force-time, power-time and velocity-time curves will not be altered by hydration status during the countermovement jumps and squat jumps.

H<sub>A1</sub>: The force-time, power-time and velocity-time curves will be altered by hydration status during both the countermovement and squat jump.

Though vertical jump height seems to be unaffected from hypohydration (Judelson, Maresh, Anderson, et al., 2007) it has been shown that the vertical ground reaction impulse was reduced in a hypohydrated vs euhydrated state (Samuel N. Cheuvront et al., 2010). As impulse is the change in momentum which is directly related to force through Newton's second law of motion, a change in force-time curve would be seen. This would

then impact the subsequent power- and velocity-time curves as the values are derived from the initial force-time curve.

H<sub>02</sub>: Electromyography (mean muscle activity and % of MVC) will not be altered by hydration status during the countermovement and squat jump.

H<sub>A2</sub>: Electromyography (mean muscle activity and % of MVC) will be altered by hydration status during the countermovement and squat jumps.

Reduction in strength/power due to hypohydration has been proposed to come from neuromuscular changes (21,31,33,85,116). Electromyography was been shown in the past to not be impacted by hydration status during isometric and isokinetic contractions (54) but have not been investigated during dynamic movements of the lower body.

H<sub>03</sub>: There will be no difference in electromyography (mean muscle activity and % of MVC) between jumping strategies in trained men between the age of 18 and 35 years.

H<sub>A3</sub>: There will be differences in the electromyography (mean muscle activity and % of MVC) between jumping strategies in trained men between the age of 18 and 35 years.

The majority of the studies conducted using the vertical jump, have used athletic populations that commonly use the vertical jump in their given sport (6,16,100). Few studies have examined a comparison of these jumping strategies in the population that is commonly used in the exercise science literature (138).

### *Operational Definitions*

Weighting Phase: Begins at the onset of data collection when the subject is stood upright and still and last at least one second.

Unweighting Phase: Begins at the onset of the movement and ends when the bodyweight is reached again, this coincides with the peak negative center of mass velocity.

Braking Phase: Begins at the end of the unweighting phase and ends when the center of mass velocity is equal to zero.

Propulsion Phase: Begins when center of mass velocity becomes positive and ends at the point of take-off.

Flight Phase: From the point of take-off to the point touchdown.

Landing Phase: Point of touchdown until the center of mass velocity returns to zero.

Force – Time Curve: Vertical force trace represent ground reaction forces over the duration the movement of interest.

Velocity – Time Curve: Velocity of the center of mass over the duration of the movement of interest.

Power - Time Curve: Product of the force and velocity measurement over the duration of the movement of interest.

Hypohydration: The state of hydration that is considered dehydrated.

Euhydration: Normal state of body water content

Dehydration: The act or process of becoming hypohydrated



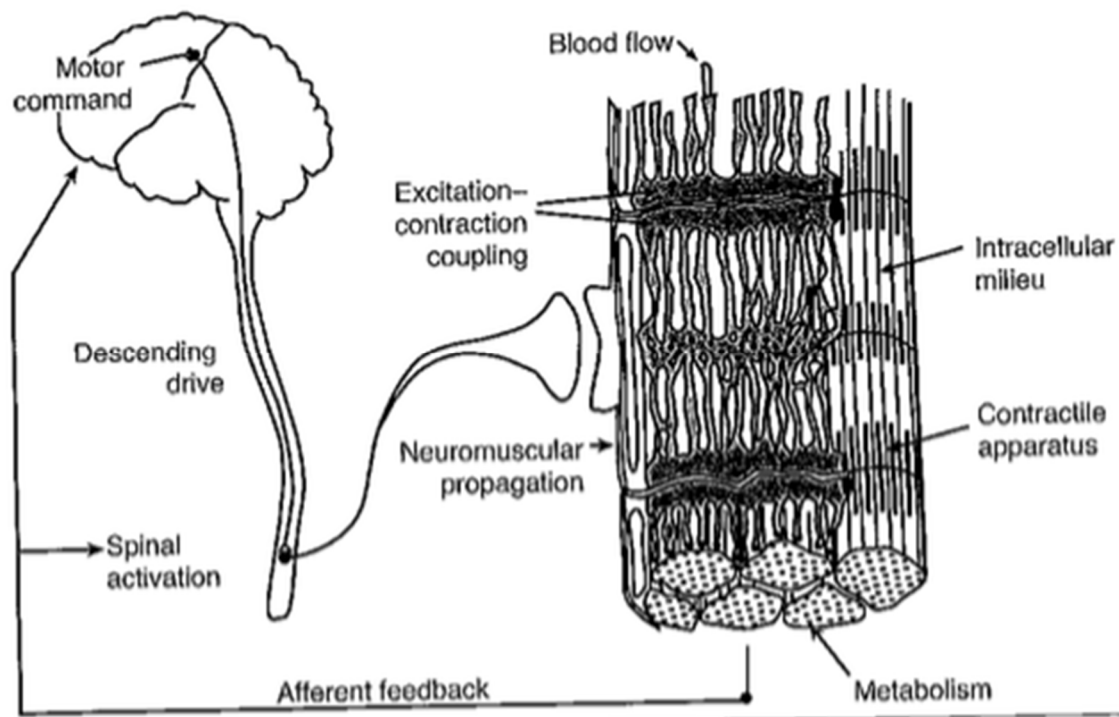
Urine Specific Gravity: Measure of urine density to assess hydration status. Used in comparison to water which has a density of 1.000.

**CHAPTER II:**  
**REVIEW OF LITERATURE**

## ***MONITORING FATIGUE IN ATHLETIC POPULATIONS***

In coaching texts on training theory and program design the term fatigue is often not explicitly defined, but rather referred to generally as a reduced performance capacity following training. The term fatigue is used in a wide variety of contexts in the literature, at times making it challenging to compare across disciplines. Abbiss and Lauren (1), defined fatigue in the field of biomechanics as a reduction in force output of a muscle, or a reduction in efficiency and in the field of physiology as a limitation of a specific physiological system such as failure in the muscles excitation – contraction coupling process.

Task failure specifically refers fatigue that develops during sustained activity and results in the inability to continue working at a given intensity. Enoka (53) describes multiple processes within the neuromuscular system that can be impaired during exercise leading to a decrement in force production capabilities. These processes include; activation of the cerebral cortex, ascending drive, afferent feedback, neuromuscular propagation, excitation-contraction coupling, muscle blood flow, and metabolism (Figure 1). Both central and peripheral factors are present in this list of processes. The separation of the central and peripheral fatigue commonly occurs at the neuromuscular junction. Neuromuscular fatigue, whether caused by central or peripheral mechanisms can have long lasting effects (52).



**Figure 1** Potential processes that can lead to impaired muscular force development. (Enoka, 2008, p 319)

### Methods for Monitoring Training Fatigue

In an ideal setting, fluctuations in performance throughout training cycles would be measured directly by a maximal test in the given event that the athlete is participating in. However, this becomes difficult for a variety of reasons. The first being that repeated maximal efforts add additional unwanted fatigue to the athlete. This becomes especially impractical during competitive seasons when competitions may occur on a weekly basis as in American football or multiple times per week as in other sports (collegiate basketball, baseball and soccer). Secondly, many sport-specific measures are difficult to assess as maximal performance in team and court sport settings. Additionally, this approach does not allow for examination of underlying changes (mechanical or physiological) associated with a change in performance (11).

The term training load is often used to describe both the internal and external loads placed on an athlete. External loads refer to the activities that are performed by an athlete, while the internal load is represented by physiological measures (137). Thus, the combination of both external and internal loads is important for training since the uncoupling or divergence of external and internal loads may differentiate between an athlete that is in a fatigued versus non-fatigued state (135). One method used to assess the fatigue in the hours and days post competition is the use of performance testing.

While it is difficult to regularly measure maximal performance in an athlete's competitive setting, an indication of their underlying mechanical and physiological capacities can be gained via a range of functional performance assessments. This method is frequently used for the assessment of neuromuscular function, where authors use test such as; countermovement (CMJ) and squat jumps (SJ), maximal strength assessments, sprints, and repeated sprints (135). The use of these assessments provide fast, efficient, and limit the amount of additional fatigue, making them feasible in team and court sport settings. For the purpose of this review, focus will be placed on the vertical jump

### *Vertical Jump Assessments*

The vertical jump is a convenient model to study neuromuscular function and fatigue (88,110). A variety of protocols have been used to assess vertical jump performance using a jump and reach apparatus (24,41,42,108), contact or switch mats (98,146), and force platforms (2,38,103,121,122). According to Taylor et al. (133) the vertical jump is one of the most popular test for performance monitoring among practitioners in high-level sport.

Despite the popularity of using the vertical jump as a performance test, there is little agreement as to which variable or variables are most important when used as a monitoring tool. This is largely due to the importance of a given variable to a given athlete or sport. This has led to a growing conflict in the literature in regards to many of the common variables that are used. Ronglan et al. (122) showed significant decreases in CMJ height over the course of 3 days of elite handball competition. Conversely, Coutts et al. (41,42) found that when using the vertical jump to measure training responses over a 6-week period that jump height provided inconsistent results. Similarly, when using the CMJ to assess in season training of youth soccer athletes vertical jump height unchanged (99). Thus, the use of jump height has been deemed insensitive in the assessment of neuromuscular fatigue. Variables including peak and mean force, rate of force development (RFD), and power have since been used to assess the effect of competition and fatigue, however they too lack consistency. This inconsistency is shown by Cormack et al, (37) where only a third (6 of 18) of the force – time curve variables from the vertical jump declined immediately post competition in elite-level Australian rules football athletes. One of the confounding factors that can explain this is the use of peak and outcome (jump height) variables (34). The neuromuscular system possesses a high level of redundancy, meaning that a given desired outcome, the system will find a way to produce the outcome by a different means if necessary. This has been shown to occur when investigating the alteration in jumping mechanics with the drop jump and the desired outcome (maximal jump height versus minimal ground contact time) (17,148). This has led to the analysis of other alternative variables such as flight time to contraction time ratio and reactive strength index modified (RSIm) (50,67). Though it may seem nonsignificant to assess other variables if jump height remains unchanged, in the

context of sport it may become a more important factor as the strategy to achieve a given vertical jump height being altered may change sport-specific outcomes.

### ***VERTICAL JUMP***

Early investigations using vertical jumps had little interest in the optimizing performance and monitoring fatigue in athletic populations. These studies were mainly concentrated on physiological and biomechanical aspects of jumping (5,28,83,97). In many of these studies the use of both the CMJ and SJ were used to find the effects of the eccentric muscle action prior to the explosive concentric action. This data and information used to help explain the storage of elastic energy in skeletal muscle (5). Additionally, the use of force platforms was introduced as a means to evaluate these effects by calculations from the force-time data that was recorded (28).

As time has progressed the use of the vertical jump as a marker of performance and as a tool to assess adaption and fatigue of a training program gained popularity (37,40,133). Regardless of the practical nature of assessing the vertical jump, there has been a wide variety of investigations reporting relationships between vertical jump performance and other explosive movements such as sprinting (12,22,44) and change of direction tasks (9,23). It has also been shown that this relationship exists between specific sports that require explosive strength and high power output such as sprint cycling (128) and Olympic weightlifting (26,62). Several investigations have found there to be a relationship between vertical jump performance and maximal dynamic strength indicating that maximal strength levels are reflected in many of the variables of the vertical jump task (26,72,74,112).

The relationship of the vertical jump and other tasks are likely related to common underlying mechanisms responsible for the performance in both movements. Specifically, the

mechanisms involving the neuromuscular systems ability to contribute to force production in both movements. One such mechanism is muscle fiber type and composition. This was examined by Bosco and Komi (18) in which thirty-four non athletes performed both CMJ and SJ and found that propulsive impulse, jump height, and RFD were significantly related to the participant's percentage of type II fibers. Similar results were found in Olympic weightlifters that type II fiber percentage was correlated to both vertical jump and weightlifting performance (63). Ballistic and explosive type muscular contractions have been shown to attain very high firing frequencies from the alpha motor neurons (48). The frequency of at which these nerve impulses travel influences both the magnitude and rate at which force is produced during muscle actions (47). Therefore, similar neuromuscular strategies are used during the vertical jump and the other ballistic explosive movements of the lower-body.

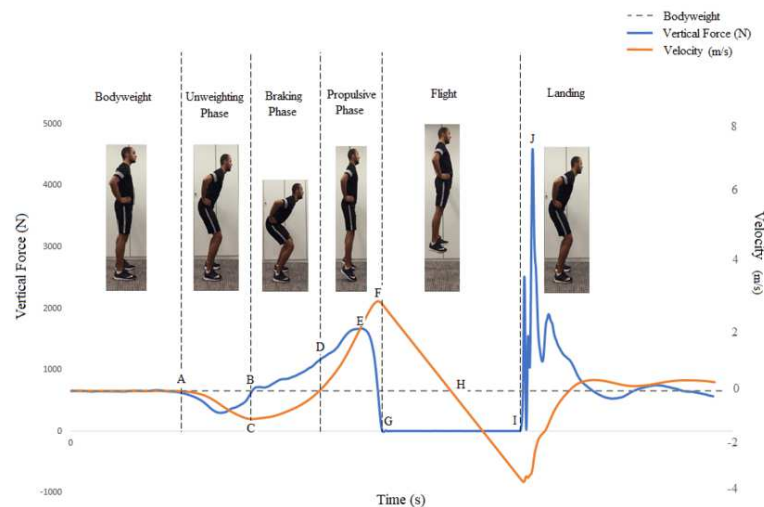
### *Phases of The Vertical Jump*

Recently, McMahon et al. (104) reviewed the key phases of the countermovement vertical jump and provided a uniform identification method of six distinct phases (Figure 2). The first phase when assessing the vertical jump being the weighing phase where the participants are to maintain a still as possible for at least 1 second. The purpose of the weighing phase is two-fold. First and most obvious being that to determine an accurate body weight (BW), but more importantly, this BW measure is used to determine the initiation of movement and further calculations using the impulse-momentum method explained later in this review. BW is determined as the mean force measured during the one second of quiet standing. Thus, it is critical that the participant stand in an upright position during this phase to ensure that both vertical velocity and displacement are equal to zero at the onset of the movement.



The second phase is known as the unweighting phase. This is the initial countermovement to the jump and occurs by a relaxation of the agonist muscles resulting in flexion of the hip, knee, and ankle joints (104). The phase begins at the onset of the movement which is identified as the instant at which BW is reduced below 5 standard deviations of the BW determined during the weighing phase (114). The unweighting phases continues to the instant which force returns to BW on the ascending aspect of the force-time curve.

Third, is the braking phase in which the COM is negatively accelerated. This phase begins when force is equal to BW and is completed when the COM velocity reaches zero. The point in which the COM velocity is equal to zero, also corresponding with the lowest point in the countermovement. The fourth phase being the propulsive phase during which the extensors muscles of the hips, knees, and ankles forcefully extend in an effort to propel the COM vertically. This phase begins once the COM velocity becomes positive and finishes at the point of take-off in which force is no longer applied to the ground.



**Figure 2:** Phases of the countermovement vertical jump and the corresponding vertical force - time and vertical velocity – time curves (29).

The flight phase is simply the time that is spent in the air from the instant of take-off to the instant of touchdown. After touchdown has occurred the one is said to be in the landing phase which formally is completed once the COM has returned to a velocity of zero. It should also be noted that when using the SJ the same phases apply from the propulsion phase through landing due the lack of the countermovement.

### **Calculations of the Force – Time Curve**

With the use of a force platform and Newton's laws of linear motion both kinematic and kinetic variables can be calculated. Such a variable as power is important to both a practitioner and researcher in the context of the vertical jump. However, from the data provided by the force platform itself only is a portion of the calculation of mechanical power ( $\text{Power} = \text{force} \times \text{velocity}$ ). Thus, to obtain the corresponding velocity – time curve one would use the impulse – momentum approach. To use this approach knowledge of the sampling rate, the vertical ground reaction force and an initial vertical velocity of zero are needed. The calculated impulse (force x time) of each time segment is determined which then is divided by the BW of the individual producing a change in velocity of the COM. When this is added to the previous velocity of the COM a new instantaneous velocity for the time interval is created. Power then can then be calculated by the product of force and velocity at that given point in time during the jump (66).

When using a linear position transducer (LPT), which common both in the literature and the field, a similar approach is taken in the calculations of these variables starting with displacement – time data. LPT measure the amount of displacement of a movement, typically by the use of a retractable wire. This allows for the differentiation of velocity-, force-, and power- time curves. Velocity is the change in displacement over time and is a simple calculation. Knowing that force is the product of mass and acceleration, next a second order differentiation for acceleration is

derived from the velocity - time data as the change in velocity over the change in time. From here force is calculated as the product of the mass of the system and the acceleration. Power then is calculated as in a similar manner as the force plate. One of the limitations assessing movements in this manner is that the further the differentiation from the original data the more error that can be brought into the calculations. Additionally, when using an LPT must be assumed that the external apparatuses (wooden dowel, barbell, etc) move in concert with the COM or else measures become invalid.

Another variable commonly calculated using the force – time curve is RFD. RFD is typically measured during the propulsion phase, starting at the 0 point.. This can then be broken down into smaller intervals that are sport relevant such as RFD100 as the ground contact time during sprinting typically occurs between 70 and 100 milliseconds (ms) (134). The use of time-bands to (0 – 10 ms, 0 – 30 ms , 0 – 50 ms, etc...) evaluate RFD has been shown to provide greater reliability then the use peak RFD (73) RFD is simply calculated as the change in force over the change in time or the slope of the force trace. Peak velocity is another variable of interest as to obtain the greatest jump height one needs to achieve the greatest velocity of their COM to project themselves into the air. Peak velocity typically occurs just before take-off (Figure 2).

### *Differences in The Squat and Countermovement Jumps*

As mentioned previously the CMJ is initiated with a relaxation of the agonist extensor muscle creating a downward movement and finishes at take-off from the ground. This takes between 500 to 1,000 ms, whereas the SJ begins from the bottom of the countermovement position and are completed at take-off and is typically range between 300 and 430 ms when measured from the initiation of upward movement (80). Besides the differences in the time to

complete the task there are other differences between the jumps as well as believed mechanisms as to what causes the difference between jump height.

Asmussen and Bonde – Peterson (5) attributed the difference in jump height to the storage and utilization of elastic energy. When comparing the SJ and CMJ it was shown that the amount of energy available in the CMJ was greater than that of the SJ allowing for a greater amount of external work to be completed. They further explained that when dropping from a height and then completing a vertical jump task that even larger amounts of energy was available increasing jump height. In later investigations it was shown that there was significant positive correlation between the SJ and CMJ force production and the fiber type percentage of the vastus lateralis. This was later refuted by Bobbert et al. (15) as it was stated that the countermovement allowed for greater joint moments to be produced at the beginning of the propulsive phase. Thus, increasing the active state (fraction of attached cross-bridges) and force before the start of the concentric muscle actions.

In more recent investigations, the use of an equation ( $CMJ - SJ$  or  $CMJ/SJ$  height) has been employed to measure the effective utilization of the braking phase during the CMJ (102,131). These show that the greater difference between CMJ and SJ suggest the greater use of the stretch-shortening cycle, however the mechanisms that are responsible for this are performance enhancement are not specified. If it is the storage of elastic energy that is the mechanism that causes this increase, then a larger difference would be a benefit. On the other hand, if the mechanism is the uptake in muscle slack as has been suggested by Van Hoogen and Bosch (80), then a larger difference suggest that the individual has a poor ability to develop pretension by coactivation.

There are several proposed mechanisms of explaining the difference in jump height (81). Before discussing the mechanisms causing the difference it is important to discuss the muscle-tendon relationship during the vertical jump task. While the CMJ is commonly used to describe the stretch-shortening cycle it is important to note which elements are stretching and shortening. While it is often assumed that during the countermovement there is an eccentric action of the fascicles of the leg muscles. Several studies have shown that if any lengthening occurs in the muscle it is typically passive and occurs in the monoarticular muscles (57–59).

The first proposed mechanism is that of the residual force enhancement. The contribution, if at all, would be minimal due to the muscle fibers only actively lengthening at slow large amplitude CMJs (90,91). With the use of computational modelling, it was shown that CMJ height was greater than SJ height when residual force enhancement was not incorporated (13). The second proposed model is an increase in muscle activation due to the stretch reflex. Muscle spindles detect both the stretch of the muscle but also the velocity of the stretch. As most countermovement's occur at a great enough velocity the lack of active muscle lengthening would not evoke the stretch reflex (81). This explains the differences in the literature as to surface electromyography (EMG) readings seen during the CMJ and SJ. These findings suggest that the stretch reflex may not be activated during fast small countermovements and will be active during the large amplitude countermovements if both the threshold velocity and length are reached (15,69,94). Nevertheless, it has been shown that the ballistic movements such as the vertical jump already require a maximal activation of motor units, thus the stretch reflex can be questioned as to any additional motor unit recruitment (94,100). The reduction of muscle slack and the buildup of stimulation is the final proposed mechanism. A countermovement moves the attachment points of the muscle-tendon unit further apart, therefore taking up any slack that

would be present from a relaxed muscle and allowing quicker force transmission (59,80). However, in the SJ the attachment points are also moved further apart therefore taking up slack as well. In the starting position of the SJ however, the forces are only high enough to counter the force of gravity. In contrast, the forces at the initiation of the propulsive phase of the CMJ the forces are much higher than that of the SJ. Thus, leading to higher jump heights (81).

### *Electromyography and The Vertical Jump*

EMG has long been used in combination with the vertical jumping task. The early investigations using EMG attempted to demonstrate the greater use and storage of elastic energy (5,28,89), the potentiation effects of the countermovement (19,138) and the muscle coordination patterns (16,83). As time has progressed so has the use of EMG as a tool in determining other factors such as the muscle activation patterns across different countermovement depths (14,90) and as well as in aiding in injury prevention (115).

One of the concerns with the use of EMG in high-velocity, ballistic movements such as the vertical jump is the normalization of the signal. While the use of maximal isometric voluntary contractions (MVC) is most commonly used in the literature as a normalization method this may not provide the same level of muscle activation as seen during the vertical jump itself. Thus, creating muscle activation percentages in excess of 100% activation. While this is an issue and has been addressed in the literature, no clear alternative has been suggested (8). While issues are clearly present in the normalization methodology it has been shown that the use of EMG during the vertical jump provides reliable data under the limitations of using surface EMG as a measurement (47,55,56,70).

## *HYDRATION*

### **Pre-Event Hydration Status**

The detrimental effects of dehydration have been well documented in the literature in regards to aerobic exercise performance. In recent years there has been several studies that have investigated hydration status both before and after training and competition (4,25,117,119,120,127,129,130,141). Much of this literature investigates fluid balance and intake during sessions as a means of maintaining hydration status during exercise (79,113,117,120,126,127). It is important to note that in all such cases the majority of the participants reported to training sessions and competition in a hypohydrated state. This finding was consistent regardless of age and training status (recreational, elite, and professional).

The criterion values used across studies were consistent with the recommendations from the National Athletic Trainers Association (NATA) and American College of Sports Medicine (ACSM) regarding hydration status measured from urine specific gravity (USG) (27,124). While the NATA position stand provides separate classifications for hydration status into minimal (USG = 1.010 – 1.020), significant (USG = 1.021 – 1.030) and severe (USG > 1.030) hypohydration, ACSM classified hypohydration as a USG measurement that exceed 1.020 (27,124). Additionally, the NATA classification provide equivalent hydration status measurements such as USG = 1.021 to 1.030 as a loss of 3 to 5 percent body mass (27). The most recent NATA recommendation (101) does not provide classification based on USG and recommends the use of USG and percentage of body mass changes in combination as to determine hydration status.

Armstrong (4), showed that over the course of a three-day outdoor collegiate tennis tournament, that both males and females arrived each day in a minimally to significant

dehydrated state (mean USG of 1.018 – 1.022). Similar findings occurred when assessing adolescent American football players over a five-day period in which athletes practiced twice daily. In this investigation between sixty and seventy percent of the participants arrived with a USG greater than 1.020 (130). Recreationally trained populations showed similar findings to those of competitive adolescents and collegiate athletes, in that the mean USG of three hundred and twenty-nine (n = 329) was  $1.018 \pm 0.007$ . Of the total sample taken 46% reported to the training facility in a hypohydrated state (USG > 1.020) and an additional 38% reported USG between 1.010 and 1.020 (129). These are important findings due to the design of study. Investigators were at the training facility prior to the participant's arrival and participants were then recruited upon arrival. This allowed for an unbiased assessment of hydration status upon arrival to the training facility. In a similar manner Volpe et al. (141), examined the pre-practice hydration status of collegiate athletes. Assessment of USG were taken prior to team practice and showed that 66% (n = 174) athletes arrived at practice with a USG > 1.020. Additionally, 13 % (n = 34) arrived with a USG in excess of 1.030. Hydration testing was a regular part of the prepractice routine experienced by the athletes and again limited the bias the results. Also, testing occurred throughout different parts of the days as teams practiced at different times (5:30 AM to 5:30 PM). There was no significant difference in hydration status in terms of time of day. This is important as the athletes tested later in the day had a greater opportunity to hydrate before practice (141).

When investigating pregame hydration status and the impact on fluid intake, Osterberg et al., 2009, found similar results in that the majority (15 of 29) of National Basketball Association Summer League players arrived in a hypohydrated state. They also found that there was no significant association between the pregame hydration status and the amount of fluid consumed



during the game. Similar results were found in elite youth soccer players during consecutive days of training (127). The authors of this investigation showed that while there was a significant positive relationship between sweat loss and total fluid intake that the athletes finished training sessions with USG measures non significantly greater than pretraining. This is of importance as on all three training days the mean pretraining USG values were greater than 1.020. Comparable results were seen in elite youth soccer athletes in a cooler climate where it was believed that climate conditions may play a role in hydration status. On average 77% of players were classified as being hypohydrated on the first and third days of three consecutive days and 62% on the second day (120). Additionally, investigators found there to be a significant reduction in body mass from pre-training to post-training indicating further dehydration.

Primary methods of weight reduction in many weight class sporting events involve fluid restriction and excessive sweat loss to reduce bodyweight at the time of competition. This acute reduction in body mass may jeopardize health and performance and regulations have been put in place in attempt to reduce health risk (119). One method that is used to prevent excess weight-cutting is to move weigh in closer to the time of competition, this reduces the amount of time that one would then have to regain body weight before competition and discouraging the use of unhealthy weight loss methods (119). It was found that regardless of weigh in time (night before or morning of competition) large amounts (89%) of elite combat sport athletes were classified as hypohydrated through the use of USG (119).

It has been established in the literature that athletes, regardless of age and ability arrive to practice and competition in a hypohydrated state the majority of the time. It has also been shown that hydration levels do not vary much during exercise, with any changes that are seen being a

greater level hypohydration. It has also been seen that the hydration status at the beginning of exercise does not have a significant impact on the fluid intake during exercise.

### **Hydration and Anaerobic Exercise**

The detrimental effects of dehydration on endurance exercise performance have been seen at a loss of 2% body mass (33). However, the effects of hypohydration on anaerobic performance are less clear than endurance exercise. This is suggested to be due to a number of confounding factors. Research has shown that dehydration of 3% of body mass is the critical level to diminish anaerobic performance (85,93). Conversely, there have been instances in which anaerobic performance was diminished with reductions < 3% of body mass (32,65). Even when there are numerous other possible confounding factors including: variations in modalities used to measure anaerobic performance, heat stress influence, and possible duration component (85,93,111).

Differing modalities used to assess anaerobic performance makes it difficult to compare findings. Tests of anaerobic performance include one – repetition maximum weight lifting (125), repeated back squats (86), unilateral leg extensions (77), vertical jump (32,77,86), 15- second Wingate anaerobic tests (30,92), single bout sprints (145), and repeated sprints (45,65). With the wide variety of modalities have been used to measure anaerobic performance, it is possible that exercise mode could be a determining factor on whether dehydration has a negative impact on performance (93,123).

In addition to the modalities chosen and the level of dehydration achieved, the methods to achieve a hypohydrated state may as well be a confounding factor. Using modes of active dehydration (exercise-induced) or passive (sauna or hot water bath) on the same day as exercise testing can have a negative impact on performance (123). The exercise used to induce

hypohydration could lead to fatigue that would hinder performance. Similarly, the heat exposure used in both active and passive dehydration could possibly lead to diminished performance in excess of the potential effects that hypohydration. It has been suggested in an attempt to isolate the effects of dehydration, protocols should be passive and conducted prior to the day of exercise testing (123).

Kraft et al. (93) suggested that a time component (time of anaerobic performance and recovery intervals during repeated bouts) may influence the effects of hypohydration on anaerobic performance. Anaerobic bouts lasting less than thirty seconds (30 sec) might experience no decrement, while those lasting over thirty seconds will. Another factor in this modality of testing are the rest periods given between intermittent anaerobic performance measures as recovery between anaerobic bouts are largely aerobic in nature (93,111).

Research suggests that there is a critical level of a body mass loss 3% for anaerobic performance to be reduced. Likewise, a multitude of other factors are possible confounding factors pertaining to hypohydration and anaerobic performance. This factors should be taken into account when investigating the effects of hypohydration on anaerobic performance.

### *Hydration and Muscular Strength*

The majority of the literature investigating the effects of hypohydration on muscular strength has focused on isometric and isokinetic strength, with unclear results. While the majority of studies have found no statically significant differences in isometric or isokinetic strength (93) however, decreases in isokinetic strength have been shown at slower velocities of 30<sup>0</sup> and 60<sup>0</sup> per second (77).

Though little research exists, hypohydration has been shown to negatively impact isotonic muscular strength. Following a passive dehydration protocol with the use of a sauna, participants' bench press 1RM was significantly reduced (125). Though the level of dehydration (1.5%) did not reach the apparent threshold for decrement in anaerobic performance, bench press was still reduced by 5% relative to a euhydrated state. These negative effects, however were negated when participants were allowed to rest and rehydrate over a two-hour period. Given the relatively small impact of hypohydration on strength, the infrequent statistical significance is not surprising, especially considering that the mean sample sizes of studies are very small ( $n = 10$ ) (86). Across all studies investigating hydration status and muscular strength there appears to be no muscle group or muscle actions that are more susceptible to hypohydration (86). In a review by Judelson et al. (86) two-thirds of studies uninfluenced by masking and exacerbating factors, resulted in a 2% reduction in strength when 3 – 4 % reduction in body mass occurred.

### *Hydration and Muscular Power*

Vertical jump performance in respect to hydration status is commonly measured as vertical jump height in most the literature. When using vertical jump height as a indicator of performance there appears to be no statistically significant difference between hypohydrated and control trials (77,85,145). Chevont et al. (32) took a different approach to the investigating the effects of hydration on vertical jump performance. It had been proposed previously that the reduction in body mass from the dehydration protocol may indeed improve performance in the vertical jump. This was believed because of an increase in the strength to mass ratio, in that muscular strength remains unaffected by hypohydration. Thus, it was hypothesized that vertical jump height should improve. Participants performed vertical jumps in both euhydrated and hypohydrated state. In

the hypohydration trial participants performed vertical jumps with and without a vest to simulate the mass lost from the dehydration protocol. Euhydrated and hypohydrated trials without the vest showed no significant difference from each other. However, a 4% reduction in vertical jump height was seen when trials were performed with the vest (32). These results also showed that the vertical ground reaction impulse was reduced in the hypohydrated trials, suggesting that any reduction in body weight is offset by an inability to produce the same level of contractile force (32,111).

Similar results have been seen when investigating fluid balance in team sport settings and the impact of hypohydration on vertical jump performance. It was again shown that hypohydration had no significant impact on maximal vertical height (111). However, Baker et al. (7) reported that there was a significant increase in the time to complete repeated jumps by 4% in hypohydrated versus euhydrated states in basketball athletes. This was similar to findings that a non-significant 19% reduction in anaerobic power after fluid restriction compared to no restriction during a basketball game (79). These findings along with the findings from discussed above suggest that perhaps vertical jump height is not affected by hydration status but the mechanics of how that jump height is produced are changed. Gutiérrez et al. (71) did however see reduction in both squat jump (4.7%) and countermovement jump (3.8%) height after a heat exposure dehydration protocol.

### **Hydration and Potential Mechanisms That Effect Performance.**

As mentioned previously, the mechanisms in which hydration effects aerobic exercise is well understood. In contrast, much less is known regarding the mechanisms in which anaerobic exercise is affected. Several mechanisms have been proposed as to what may cause any

decrement in performance including; cardiovascular, metabolic, cognition and neuromuscular mechanisms. (85,111). While both cardiovascular and metabolic mechanisms are useful in the explanation of aerobic performance decrement it appears that these insufficiently explain potential effects on muscular strength and power (85). The mechanism that is most often used as an explanation in the literature for a reduction in anaerobic performance is an impairment of the neuromuscular system (21,60,61,79,85,107,140,142). While this is the prevailing belief, there is a lack of evidence that conclusively suggests anaerobic performance is impaired by the neuromuscular system. Bowtell et al. (21) investigated the effect of hypohydration in peripheral and corticospinal excitability and voluntary activation and concluded that different neural strategies seem to be adopted in hypohydrated and euhydrated conditions. The authors stated that the increase in peripheral muscle excitability evident in the hypohydrated condition was not sufficient to preserve performance (decreases in isometric and eccentric isokinetic) in the presence of reduced muscle contractility or impaired excitation-contraction coupling.

There is limited EMG data which again is inconclusive. Early investigations using EMG to investigate the effect of hypohydration was conducted on participants taking part in aerobic based activity and during fatiguing contractions. Bigard et al. (10) found that the hypohydration induced earlier onset of fatigue which in turn associated with early changes in EMG spectral parameters. They additionally, stated these results were unclear whether the alternations could be attributed to a biochemical modification or perception of effort from the dehydration protocol. Ftaiti et al. (64) showed that after a 40 minute treadmill EMG amplitude was reduced for both isometric and slow isokinetic (60 °/s) muscle actions while faster isokinetic (240 °/s) velocities were unaffected. A 2% loss in body mass was used as an indication of a hypohydrated state while no other measure of hydration status was used.

When using a passive dehydration protocol that limited the consumption of water to 500 milliliters (mL) prior to the arrive of testing, it was found that isometric and isokinetic strength were unaffected by the reduction in body mass from approximately 73 kilograms (kg) to 71 kg and a USG of 1.027. Additionally, mean EMG amplitude was unaffected by the dehydration protocol at varying levels of MVC and isokinetic testing (54). While these results suggest that the neuromuscular system may not play a role in explaining reduction of force output, it should be noted that these investigations were performed on isometric and isokinetic muscle actions leaving a void in the literature as to dynamic and ballistic muscle actions as those seen in sporting events.

**CHAPTER III**  
**MANUSCRIPT I**



**The Effect of Hydration State on Countermovement and Squat Jump Performance**

To be submitted to the Journal of Strength and Conditioning Research

## INTRODUCTION

Investigations into hydration status of athletes have shown that the majority arrive at training sessions and to competitive settings hypohydrated and continue further into that hypohydration during training sessions. These individuals lack the ability to become rehydrated before subsequent sessions regardless of fluid consumption during activity (113,123,141). A substantial body of literature exists into the effects of poor hydration practices on aerobic based performance, however the same cannot be said for anaerobic performance (85). The vertical jumping task is commonly used as a method to assess the effect of hydration on anaerobic power with conflicting findings as to how much impact hypohydration has on task performance (32,71,77,79).

With the exception of one investigation (139), in which jump performance was improved, jump performance seems to be unaffected by hypohydration. The vertical jump is performed against the resistance of one's own body mass, a reduction in body mass due to hypohydration should improve vertical jump performance as long as strength or power is maintained as this would then improve the strength to mass ratio (32). This is an interesting finding as it has appeared that muscular strength independent of body mass, indicates a small negative impact (1-3%) which may not impact the strength to mass ratio (31,85,123). However, it is seen consistently in the literature that jump height is not significantly different between hydration classifications (71,77,79). There has been one investigation that has taken the change in body mass into consideration and held body mass constant across hydration classifications with the finding that jump height, peak velocity, and impulse were reduced in a hypohydrated state during the countermovement jump (CMJ) (32).

As competition and training schedules have become more dense, jump testing has become a common tool used in the assessment of athletes to have an understanding of their level of neuromuscular fatigue and/or readiness for subsequent training and competition (35,67,144). Specifically the CMJ and the squat jump (SJ) are the most commonly used as tools in the assessment and monitoring of athletes by strength and conditioning professionals (133). This is due to the ease of implantation and the lack of additional fatigue that the test generates. CMJ consist of being where the athlete starts in a standing position and begins a downward movement, which is immediately followed by an explosive upward motion leading to takeoff from the ground. SJ begin with moving into a semi-squatting position and holding this position for a period of time, typically about 3 seconds. This is then followed by an explosive concentric only upward movement to achieve takeoff. The use of variables outside of jump height for both jumping techniques have been suggested as jump height alone may not provide the sensitivity needed to understand neuromuscular fatigue, as well as allowing for a more precise examination as to how a particular jump height was obtained (42,67,68). It has been shown that jump height alone may stay constant through a change in strategy during the movement itself obtain a given height (17,148). While maintaining jump height seems to be important, a shift in strategy to achieve a given height may not be optimal during sport-specific situations where temporal restrictions may be placed on an individual. Typical variables include the use of peak and mean values of force, velocity and power, as well as other time related variables such as time to peak, contraction time and reactive strength index modified (RSIm) (50,67).

With the increase in popularity of using assessments such as CMJ and SJ testing, it is important to have an understanding of potential factors that could influence the results of the assessment. As discussed previously, athletes have a tendency to arrive at training sessions

hypohydrated and perform either the CMJ or SJ or both to assess their neuromuscular fatigue. While it is seen that jump height itself may not change significantly based on hypohydration, other variables such as jump velocity and impulse appear to be impacted. Thus, the purpose of this investigation is to examine the impact of hydration status on variables commonly used in the assessment of neuromuscular fatigue with both the CMJ and SJ.

## **METHODS**

### **Experimental Approach to the Problem**

A counterbalanced crossover design was used to assess the effect of hydration status on selected variables associated with both countermovement and squat jump performance. Participants visited the laboratory for a total of four times, one familiarization session and three experimental sessions. During the first visit participants were screened for exclusionary criteria and were familiarized with test protocols for both the countermovement (CMJ) and squat jump (SJ).

### **Subjects**

Twenty-five ( $n = 25$ ) recreationally trained males (height  $180.236 \pm 8.00$  cm, body mass  $85.15 \pm 12.23$  kg) between the age of 18 and 35 (age  $23.85 \pm 2.81$  years) participated in this investigation. All subjects were physically active for the 6 months preceding data collection and were deemed to be free of injury and cleared for physical activity by the physical activity readiness questionnaire (PAR-Q). Informed consent approved from the University Institutional Review Board was obtained.

## **Procedures**

### **Hydration Assessment**

Following familiarization participants were randomized into one of three hydration conditions for the first experimental visit. This same procedure was completed at the end of sessions one and two for the subsequent session. For hypohydrated sessions participants were restricted to five-hundred milliliters (500 ml) of water in the 12 hours prior to arrival in the laboratory with no fluid to be consumed in the two hours immediately prior to visit. Testing sessions began between the hours of 0800 and 1000 am. This allowed for a predominately passive overnight fluid restriction to reduce potential confounding effects of exercise and/or heat in the achievement of a hypohydrated status. During euhydrated sessions the participants were encouraged to consume water at a rate higher than they would typically consume on a normal day. While on the control day participants were given no instruction in regard to fluid intake.

After arriving to the laboratory for the experimental sessions participants were provided a sterile urine specimen cup to provide a mid-stream urine sample of less than one hundred milliliters (100 ml). Once the urine sample was collected, urine specific gravity (USG) was assessed using a digital pen refractometer (Atago USA Inc, Bellevue, WA) to ensure that the participants are in within the value range to be classified as being hypohydrated, ( $USG \geq 1.022$ ) or euhydrated ( $USG < 1.015$ ) for that given session. While the traditional criteria value for hypohydration using USG is  $\geq 1.020$  in the literature, to ensure differences between sessions a higher threshold for hypohydration was used as well as a lower value for euhydration sessions (27). In the event that the hydration status for that given session was not achieved participants

were asked to return to the laboratory in two hours to reassess hydration status and determine if testing can be conducted on that day. Once classification had been deemed acceptable participants completed the standardized warm up.

### **Jump Testing**

Both CMJ and SJ were performed using a wooden dowel (1.0 kg) placed across the shoulders in a high bar squat position. Participants completed one set of three jumps at a self-selected foot position and to a self-selected depth. They were instructed to jump as explosively as possible to achieve maximal height (3). It has been shown that when using a self-selected depth that both maximal force and power were higher than using a standardized starting position in the SJ (118). Participants were also instructed to maintain contact between the wooden dowel and the upper back at times throughout the movement. Participants were instructed to remain as still as possible prior to the initiation of the jump to allow for body mass to be determined and then used in the calculation of variables of interest during data analysis (104). The use of a 3, 2, 1, jump countdown was used for each trial.

Ground reaction force data was collected using a 600 x 400-mm force platform (Bertec Corp, Columbus, OH, USA). Force data was collected at 1000 Hz. All variables derived from the force platform were calculated using the impulse – momentum method. The propulsive phase of each CMJ trial was identified using methods described Chavda et al. (29) and McMahon et al. (104). Similar processing was adapted to SJ trials with the exclusion of an unweighting and braking phase. Thus, finding the mean of one second of weighting once at the self-selected depth and then identifying the first instance in which GRF was greater than 5 standard deviations (SD) above the mean of the one second weighting to signify the initiation of movement. From

this point forward methods were identical to those used in the CMJ and described by Chavda et al. (29). Additionally, data was collected using a linear position transducer (LPT) (Kinetic Performance, Australia). The LPT used a tethered cord attached to the right side of the wooden dowel to extract displacement-time data. From this data, movement velocities and the subsequent accelerations are calculated through differentiation (43). Force and power data from the LPT was then derived from the velocity and acceleration data previously calculated. Only the propulsive phase of the CMJ was used in determination of peak and mean values of the force, velocity, and power. Time to peak for each of the previous mentioned variables occurred from the initiation of the concentric phase to the point at which the peak value was measured.

Additionally, impulse was calculated using force data collected from the force platform. The impulse was calculated at each frame as the mean net force of the current frame and the previous frame multiplied by 0.001 as this was the period of time between frames. All impulse calculations were then summed together from the initiation of the propulsive phase through takeoff to determine concentric impulse (29). Reactive strength index was calculated as a ratio of the jump height over time to takeoff (50). Time to takeoff consisted of the time from which movement was detected to the time of takeoff using the methods described by Chavda et al. (29). Finally, concentric duration was calculated as the time from initiation of the propulsive phase to the time of takeoff.

### **Statistical Analysis**

A within-subject repeated measures analysis of variance was used to assess the effect hydration on each variable of interest in both the CMJ and SJ. Mauchly's Test of sphericity was used test the assumption of sphericity for each variable. If the assumption was violated a

Greenhouse – Geisser correction was used. Least significant difference post hoc analysis was used to determine where differences existed.

Additionally, difference scores between control and hydration conditions were calculated for all variables from both instruments and both jumping techniques. Paired sample t-tests were used to compare differences between the change from control to hypohydrated and euhydration conditions between instruments and jumping techniques.

All statistics were run in SPSS version 25 (IBM, Chicago, IL). An a priori alpha level of 0.05 was used in all analysis. Effect sizes are presented as Cohen's *d* and interpreted using the criteria of trivial (0.0 – 0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), very large (2.0) and nearly perfect (4.0 or greater) as suggested by Hopkins (82). Effect sizes were first calculated as eta-squared values then converted to Cohen's *d* to make for comparisons to other investigations (36). During data collection a LPT hardware malfunction caused the loss of 5 participant's data for various conditions. Thus, the total number of participants used in analysis for the LPT was twenty ( $n = 20$ ).

## **RESULTS**

All results are presented as mean  $\pm$  *SD*. CMJ and SJ data for all variables are presented in Table 2, Table 3 and Table 4, respectively. No differences were seen between body mass in the three hydration conditions ( $p > 0.05$ ) (Table 1). Significant differences were seen between USG levels in each of the testing sessions ( $F_{2,48} = 158.55, p < 0.001, d = 5.15$ ) (Table 1).



In the CMJ significant differences were seen in peak force ( $F_{2,48} = 3.32, p = 0.045, d = 0.74$ ) from force platform data. Post hoc results showed that the euhydrated state had a greater peak force than the hypohydrated condition ( $p = 0.025$ ) with euhydrated having no significance difference from the control condition ( $p = 0.085$ ). Additionally, mean force measures obtained from the force platform revealed significant differences ( $F_{2,48} = 4.74, p = 0.013, d = 0.89$ ). Post hoc results showed that the hypohydrated condition was significantly lower than both the control ( $p = 0.008$ ) and euhydrated ( $p = 0.028$ ) conditions. No other differences were seen between any other variables in the CMJ regardless of measurement device.

SJ analysis showed that multiple variables were significantly different using both measurement methods. Differences were observed in peak force derived from the LPT ( $F_{2,38} = 3.46, p = 0.042, d = 0.85$ ). Post hoc results showed that the hypohydrated condition was significantly lower than both the control and euhydrated conditions ( $p = 0.049$  and  $p = 0.026$ , respectively). Additionally, peak power from the LPT showed significant differences ( $F_{2,38} = 4.88, p = 0.013, d = 1.01$ ) between conditions with euhydration being greater than the hypohydration ( $p = 0.006$ ). Peak velocity and mean power both showed no statically significant differences, however moderate effect sizes were seen ( $p = 0.057, d = 0.81$  and  $p = 0.068, d = 0.78$ , respectively). Time to peak power using the LPT also showed significant differences between conditions.

Similar to the LPT, peak power was significantly different between conditions ( $F_{2,45} = 3.99, p = 0.026, d = 0.85$ ) when using the force platform. Hypohydration exhibited the lowest output and was different from the euhydration ( $p = 0.012$ ). Mean power also showed difference between conditions ( $F_{2,45} = 4.42, p = 0.018, d = 0.90$ ) with hypohydration being significantly lower than both the euhydration and control conditions ( $p = 0.004$  and  $p = 0.047$  respectively).

Both peak and mean velocity derived from the force platform were different between conditions ( $F_{2,45} = 7.081$ ,  $p = 0.002$ ,  $d = 1.17$  and  $F_{2,45} = 6.043$ ,  $p = 0.005$ ,  $d = 1.05$  respectively). In both the peak and mean hypohydration was significantly lower than euhydration ( $p = 0.003$  and  $p = 0.002$  respectively) and control ( $p = 0.009$ ) conditions.

Additionally, in the SJ differences were seen in jump height calculated from the force platform ( $F_{2,45} = 6.06$ ,  $p = 0.005$ ,  $d = 1.05$ ) with hypohydration having lower heights than both the euhydration ( $p = 0.004$ ) and the control ( $p = 0.015$ ). As well as differences were seen in impulse during the SJ ( $F_{2,45} = 7.419$ ,  $p = 0.002$ ,  $d = 1.16$ ) with hypohydration being lower than both the euhydration ( $p = 0.002$ ) and control ( $p = 0.011$ ) conditions.

Significant differences were seen between LPT and force plate during the SJ in the change from control to hypohydrated conditions for peak force and peak velocity ( $t(19) = 3.43$ ,  $p = 0.003$ ,  $d = 0.49$  and  $t(19) = -2.51$ ,  $p = 0.022$ ,  $d = 0.68$  respectively). Differences were seen during the CMJ change from control to euhydration in mean force between the force platform and the LPT ( $t(19) = -17.02$ ,  $p < 0.001$ ,  $d = 5.77$ ). Comparing the change from control to euhydration between CMJ and SJ differences were seen in the force platform mean force ( $t(19) = 16.329$ ,  $p < 0.001$ ,  $d = 5.23$ ).

**Table 1: Body mass and Urine Specific Gravity across conditions**

	Control	Hypohydrated	Euhydrated
Body Mass (kg)	85.20 ± 12.76	84.61 ± 12.56	85.63 ± 12.66
Urine Specific Gravity	1.0178 ± 0.004*	1.0238 ± 0.002*	1.0067 ± 0.004

\* = significantly greater than euhydrated at  $p < 0.001$  level

**Table 2: Hydration Status on Countermovement Jump Performance (Mean ± SD)**

	Force Platform			LPT		
	Control	Hypohydrated	Euhydrated	Control	Hypohydrated	Euhydrated
JH (cm)	35.2 ± 0.06	34.8 ± 0.06	34.8 ± 0.06	44.1 ± 0.05	43.4 ± 0.06	44.4 ± 0.05
PF (N)	2067.36 ± 303.36	2059.77 ± 318.81*	2107.73 ± 317.22	2557.43 ± 371.43	2489.94 ± 440.77	2550.67 ± 389.26
MF (N)	1183.24 ± 151.59	1152.54 ± 144.91*^	1171.29 ± 144.21	1805.28 ± 224.94	1788.85 ± 250.43	1801.91 ± 235.22
TTPF (s)	0.091 ± 0.08	0.101 ± 0.08	0.067 ± 0.08	0.073 ± 0.07	0.076 ± 0.06	0.045 ± 0.05
PV (m/s)	2.77 ± 0.23	2.74 ± 0.19	2.74 ± 0.18	3.32 ± 0.30	3.33 ± 0.32	2.74 ± 0.34
MV (m/s)	1.70 ± 0.17	1.68 ± 0.15	1.68 ± 0.14	2.11 ± 0.20	2.05 ± 0.19	2.10 ± 0.08
TTPV (s)	0.270 ± 0.05	0.270 ± 0.05	0.278 ± 0.04	0.249 ± 0.04	0.253 ± 0.06	0.255 ± 0.05
PP (W)	4586.68 ± 668.96	4557.18 ± 655.64	4563.70 ± 614.45	5704.26 ± 371.43	5687.86 ± 440.77	5542.27 ± 942.10
MP (W)	1687.77 ± 212.35	1649.85 ± 220.11	1678.05 ± 216.98	3338.60 ± 508.04	3240.18 ± 516.58	3334.01 ± 492.19
TTPP (s)	0.234 ± 0.05	0.234 ± 0.05	0.233 ± 0.05	0.181 ± 0.06	0.192 ± 0.07	0.193 ± 0.06

JH = jump height; PF = peak force; MF = mean force; TTPF = time to peak force; PV = peak velocity; MV = mean velocity;  
TTPV = time to peak velocity; PP = peak power; MP = mean power; TTPP = time to peak power; LPT = linear position  
transducer

\* = significantly different from euhydrated ( $p < 0.05$ )

^ = significantly different from control ( $p < 0.05$ )

**Table 3: Hydration Status on Squat Jump Performance (Mean  $\pm$  SD)**

	Force Platform			LPT		
	Control	Hypohydrated	Euhydrated	Control	Hypohydrated	Euhydrated
JH (cm)	33.2 $\pm$ 0.03	31.3 $\pm$ 0.06** <sup>^</sup>	33.9 $\pm$ 0.06	36.0 $\pm$ 0.06	36.5 $\pm$ 0.05	36.6 $\pm$ 0.08
PF (N)	2118.12 $\pm$ 382.88	2122.45 $\pm$ 419.59	2215.86 $\pm$ 562.59	2453.72 $\pm$ 416.06	2310.11 $\pm$ 419.78* <sup>^</sup>	2431.22 $\pm$ 404.27
MF (N)	1578.11 $\pm$ 214.56	1547.47 $\pm$ 229.56	1588.15 $\pm$ 217.26	1759.07 $\pm$ 252.81	1684.87 $\pm$ 252.60	1745.53 $\pm$ 238.82
TTPF (s)	0.246 $\pm$ 0.09	0.246 $\pm$ 0.09	0.244 $\pm$ 0.08	0.095 $\pm$ 0.05	0.104 $\pm$ 0.05	0.105 $\pm$ 0.06
PV (m/s)	2.69 $\pm$ 0.22	2.61 $\pm$ 0.21** <sup>^^</sup>	2.72 $\pm$ 0.21	2.97 $\pm$ 0.33*	2.98 $\pm$ 0.21*	3.08 $\pm$ 0.27
MV (m/s)	1.25 $\pm$ 0.11	1.19 $\pm$ 0.10** <sup>^^</sup>	1.26 $\pm$ 0.12	1.75 $\pm$ 0.17	1.71 $\pm$ 0.14	1.75 $\pm$ 0.17
TTPV (s)	0.321 $\pm$ 0.09	0.362 $\pm$ 0.20	0.325 $\pm$ 0.07	0.239 $\pm$ 0.06	0.253 $\pm$ 0.06	0.250 $\pm$ 0.05
PP (W)	4668.38 $\pm$ 648.02	4506.02 $\pm$ 697.11*	4756.81 $\pm$ 608.36	5097.00 $\pm$ 716.21	4896.66 $\pm$ 720.79*	5402.05 $\pm$ 889.23
MP (W)	1984.66 $\pm$ 296.27	1870.88 $\pm$ 301.17** <sup>^</sup>	2023.45 $\pm$ 300.59	2746.21 $\pm$ 419.21	2642.99 $\pm$ 348.93*	2810.89 $\pm$ 394.33
TTPP (s)	0.286 $\pm$ 0.08	0.283 $\pm$ 0.08	0.284 $\pm$ 0.07	0.175 $\pm$ 0.06	0.197 $\pm$ 0.07 <sup>^</sup>	0.192 $\pm$ 0.06

JH = jump height; PF = peak force; MF = mean force; TTPF = time to peak force; PV = peak velocity; MV = mean velocity; TTPV = time to peak velocity; PP = peak power; MP = mean power; TTPP = time to peak power; LPT = linear position transducer

\* = significantly different from euhydrated at (p < 0.05) level

\*\* = significantly different from euhydrated at (p < 0.01) level

<sup>^</sup> = significantly different from control at (p < 0.05) level

<sup>^^</sup> = significantly different from control at (p < 0.01) level

**Table 4: Hydration Status Impact on Time Dependent Variables Calculated using the Force Platform**

	CMJ			SJ		
	Control	Hypohydrated	Euhydrated	Control	Hypohydrated	Euhydrated
Concentric Duration (s)	0.296 ± 0.05	0.296 ± 0.05	0.297 ± 0.05	0.350 ± 0.08	0.351 ± 0.08	0.346 ± 0.06
Impulse (Ns)	121.562 ± 20.23	116.03 ± 19.36	119.54 ± 19.53	228.41 ± 24.06	221.39 ± 26.42* <sup>Λ</sup>	234.55 ± 29.09
RSIm	0.74 ± 0.22	0.71 ± 0.20	0.72 ± 0.16	0.72 ± 0.23	0.72 ± 0.26	0.78 ± 0.22

RSIm = Reactive Strength Index Modified

\* = significantly different from euhydrated at (p < 0.01) level

Λ = significantly different from control at (p < 0.05) level

## DISCUSSION

This investigation sought to examine if hydration status influenced performance in both the CMJ and SJ. The main finding from this investigation was that differences were observed between variables based on both hydration status and measurement technique. As assessments of neuromuscular fatigue continue to be used prior to training sessions and competition, it is important to identify factors that may have an impact on the outcome of the assessment. The use of the vertical jumping task is common in the literature and in practice as a means of assessing lower-body power output and is commonly used in identifying how hydration plays a role in anaerobic performance (31,32,71,79,86,145).

The finding that jump height was not impacted by hydration status is consistent with previous investigations evaluating hypohydration on anaerobic performance using the CMJ (30,32,71,77,86). However, this is conflicting to the results of Chevront et al (32) where a reduction in CMJ jump height was seen when holding mass constant with the use of a weight vest. Though not significantly different, mass was reduced during the hypohydrated condition by less than 1% to the control condition. Similarly mass was increased by less than 1% in the euhydrated condition and similar jump heights were maintained. The finding that jump height was significantly impacted in the SJ is conflicting to previous investigations that used the squat jump in the hypohydration literature (71,79). Gutierrez et al. (71) found that jump height was reduced by a nonsignificant 4.7 % in a sample of 6 men after a dehydration protocol. The findings in the present investigation can be explained by the significant differences seen in the peak velocity. As velocity is used in the calculation of jump height from the force platform a higher velocity in the euhydrated state would explain the greater jump height. Though not significantly different, the LPT found a similar result in that the peak velocity was higher in the

euhydrated condition over both the control and hypohydrated conditions while still showing a moderate effect size ( $d = 0.80$ ).

It was important to this investigation to assess how other variables outside of jump height that are commonly used by practitioners in their assessments of athletes. It has been suggested by some that the use of jump height as simple measure to indicate early overreaching (143,144,146), while others have suggested that jump height lacks the sensitivity needed to detect changes that would show signs of neuromuscular fatigue (41,42). This has led to the use of both kinetic and kinematic variables in assessing jumping performance (37,67) These include peak and mean force, velocity, and power as well as time to peak for the given variables. In addition other alternative variables used in the concentric duration, impulse, and reactive strength index modified (67).

Conversely, to the findings of Chevront et al. (32) who also used a force platform, the present investigation found a reduction in both peak and mean force during the CMJ when hypohydrated. While not significantly different it can be seen that euhydrated condition had lower time to peak force then the hypohydrated and control conditions with a moderate effect size ( $d = .79$ ). Thus, a small change in the technique used may have been present to offset the difference in force to produce the same jump height. When time to peak is calculated as a percentage of the concentric duration, the euhydrated condition reached its peak force 12% faster than the hypohydrated. The neuromuscular system possesses a high level of redundancy, meaning that for a given desired outcome, the system will find a way to produce the outcome by different means if necessary. This has been shown to occur when investigating the alteration in jumping mechanics with the drop jump and the desired outcome (maximal jump height versus minimal ground contact time) (17,148).

Impulse is calculated as the product of force and time and is important to how much change occurs in our motion through the impulse – momentum theorem, where momentum is the product of mass and velocity. With regard to the impulse calculated in this investigation, a moderate effect ( $d = 0.66$ ) was seen between conditions in the CMJ with the hypohydrated condition being the lowest of the three. This is similar to the previous findings that also assessed the CMJ impulse and hydration (32). In the present investigation force was reduced where velocity was maintained, which is the direct contrast to the findings of Cheuvront et al (32), where a reduction in velocity was seen and no difference between force during the CMJ. The present investigation added a component for time that was not a part of the previous investigation. We can see that the concentric duration remained unchanged between conditions, thus the reduction in force seen in the hypohydrated potentially caused the lower impulse. During the SJ however, impulse was significantly higher in the euhydrated and control conditions than that of the hypohydrated. With no differences in time and a small to moderate effect size seen with peak force ( $d = 0.46$ ). The results of the previous study by Cheuvront et al. (32) are more similar to the findings of the SJ in the present study were jump height, peak velocity and impulse all showed differences by conditions.

In regards to the SJ, differences were found outside of jump height in both peak and mean velocity and power. While peak values are commonly sought as a variable of interest, the value is for only one instantaneous moment in time, consequently only representing a very small portion of the entire movement. The inclusion of mean values provides a more robust representation of the variable over the entire movement. As power was calculated as the product of force and velocity at each time point a reduction in either force or velocity would have an impact on power. As both peak and mean velocity was lower in the hypohydrated condition it



would be expected that power would be reduced as well. Additionally, the small reductions in force that are seen would add to the reduced peak and mean power values. To the authors knowledge this is the first investigation to use the variables outside of jump height in trying to identify the impact of hydration with the SJ. Additionally, it should be noted that both the control and euhydrated conditions are different from the hypohydrated, but not different from one another for both velocity and power. This is relevant as the mean USG on the control day would be classified as euhydrated based on the critical values set forth in the literature (27). The only variable where differences were seen between euhydrated and control sessions was that of peak velocity from the LPT.

In this investigation both a force platform and LPT were used simultaneously during each trial. It was been shown that the use of the specific LPT in this investigation to be deemed both reliable and valid (43). This is important for two reasons. First, being that in regards to peak power both methods found that the during euhydrated condition greater values were seen than the hypohydration condition using both methods in the SJ. Though peak power is obtain through different calculation methods both revealed the impact that hydration status can play. Secondly, while the force platform is the gold standard of measurement used in vertical jump assessments, its practical use in a field-based setting is still difficult for many practitioners at this time and the use of LPT devices work as a more practical solution while still being able to detect significant devices between hydration states.

Significant differences that were observed between the force platform and LPT differences scores between control to the hypohydration in peak force and peak velocity as well as the euhydration mean force in the CMJ can be explained by possible measurement error as the participants could have lost contact with the wooden dowel on their upper back. This is

important as the assumption is made that the dowel is attached to the individual, thus creating a mechanical system. If contact is not maintained you then are measuring the movement of the dowel itself and not the system of the dowel and the individual. Additionally, in regard to differences in the force measure specifically, the force platform is measuring force directly while the LPT is estimating force through double differentiation of the displacement-time data where any error in the measurement would be compounded.

## **PRACTICAL APPLICATION**

As strength and conditioning professionals continue to use both the CMJ and SJ as assessment tools, it is important to have an understanding of how additional factors can play a role in the results of the assessment. As many athletes arrive to both training and competition hypohydrated, it is important to consider how this impacts the variables of interest and modifications to training programs based on the results of those evaluations. Additionally, it can be seen that while both the CMJ and the SJ are impacted by hydration status, the SJ seems to be influenced to a greater extent. Moreover, while the use of force platforms has become more common the use LPT is still more feasible for many practitioners in their assessments, however it can be seen that difference between methods are observed in this investigation.

**CHAPTER IV**  
**MANUSCRIPT II**

**Impact of Hydration Status on Electromyography and Ratings of Perceived Exertion  
During The Vertical Jump**

To be submitted to the International Journal of Sports Physiology and Performance

## INTRODUCTION

Hypohydration has been shown to have a detrimental influence on aerobic based exercise, with altered cardiovascular function and metabolic factors leading to early onset fatigue (85). While important, maximal anaerobic performance relies less on both cardiovascular and metabolic function than aerobic performance. The vertical jumping task is commonly used as a means to assess lower-body power output and is commonly seen in the hypohydration literature as tool to measure the effect of hydration status on anaerobic performance (85). The more common suggestion that is made to the possible mechanisms of a decrease in anaerobic performance from hypohydration is centered around a change in neuromuscular function if any decrement is seen at all (60,79,136,140,142). Though this mechanism is commonly suggested as the means to a reduction in performance, results from previous investigations are limited and inconclusive (10,54,64,136). Previous investigations that have used electromyography in the assessment of neuromuscular changes from hydration status have done so with isokinetic and isometric muscle actions, thus making it more difficult to translate to the dynamic task seen during most anaerobic activities (54,77).

Electromyography (EMG) is commonly used to examine neuromuscular function during different hydration status and has shown that changes in neuromuscular function do not seem to be present (10,54,64,77,85,136). Evetovich et al, (54) saw no differences in EMG amplitude between hypo- and euhydrated conditions during both isometric and isokinetic contractions of the biceps brachii. Additionally no changes were seen in torque during those same contractions. Similar results were seen by Hayes and Morse (77) during maximal voluntary contractions of the knee extensors (vastus lateralis) at progressively greater hypohydration in regards to EMG amplitude. However, a change in isometric strength and low velocity isokinetic strength ( $30^0 \text{ s}^{-1}$ )

was seen. Furthermore, no decrease in countermovement jump height was seen during the progressive hypohydration as this was used as a measure of lower-body power output (77). As high velocity isokinetic strength was maintained throughout the progressive dehydration, a subsequent increase in jump height should occur through an increase in the strength to mass ratio, as hydration status was determined by reduction in body mass.

It has been shown that hydration status has little to no impact to the vertical jump height regardless if the countermovement or squat jump is used (30,32,71,77,79). However, it has been shown that jump height may not be the variable that best indicates a potential decrement in jumping performance as reductions in peak velocity and impulse have been seen when body mass is held constant (32). This is interesting as some have suggested that jump height alone may not be indicative of presenting neuromuscular fatigue though the vertical jumping task is widely used as an assessment tool of neuromuscular fatigue in athletic populations (41,42,133). This has resulted in the use of variables calculated from jump height such as the reactive strength index modified which takes into account the time needed to reach a given jump height, thus creating a ratio of jump height over time to takeoff (50). Moreover, it has been shown that ratings of perceived exertion and mood ratings have been impacted by hydration conditions both in aerobic and anaerobic based activity (46,84,106).

Athletes are classified as being in a hypohydrated state commonly before the onset of training sessions and competition (113,141). It is important then to understand how assessments commonly used such as the CMJ and SJ can be impacted by other factors that athletes face such as hypohydration, while also looking at the proposed mechanism to a reduction in performance concurrently. Thus, the purpose of this study was to assess the impact of hydration status on mean muscle activity during the propulsive phase of both the CMJ and SJ. Secondly, this study

sought to find if ratings of perceived exertion and mood ratings were impacted by hydration state during the vertical jumping task.

## **METHODS**

### **Subjects and Design**

Twenty recreationally trained males (height  $181.03 \pm 8.61$  cm, body mass  $85.24 \pm 12.13$  kg) between the age of 18 and 35 (age  $23.95 \pm 2.67$  years) participated in this investigation. All subjects were physically active for the 6 months preceding data collection and were deemed to be free of injury and cleared for physical activity by the physical activity readiness questionnaire (PAR-Q). Informed consent approved from the University Institutional Review Board was obtained. A counterbalanced crossover design was used to assess the effect of hydration status on the muscle activation of both the countermovement and squat jump. Participants visited the laboratory for a total of four times, one familiarization session and three experimental sessions.

### **Methodology**

When first arriving to all experimental sessions subjects were provided a sterile urine specimen cup to provide a mid-stream urine sample of less than 100 milliliters (mL). Once the urine sample was collected, urine specific gravity (USG) was assessed using a digital pen refractometer (Atago USA Inc, Bellevue, WA) to ensure that the participants fell within the value range to be classified as being hypohydrated, ( $USG \geq 1.022$ ) or euhydrated ( $USG < 1.015$ ) for that given session. To achieve the hypohydration, subjects were restricted to 500 mL of water in the 12 hours prior to arrival to the visit. All visits were conducted prior to 1000 am, thus the majority of the time spent in a fluid restriction was during periods of sleep. Euhydration was achieved by consuming water at a rate greater than normal daily consumption. No instructions

were given as to water consumption for the control visit. In the event that the hydration status for either experimental session was not achieved participants were asked to return to the laboratory in two hours to reassess hydration status and determine if testing can be conducted on that day. Once classification had been deemed acceptable subjects were prepped for maximal voluntary contractions (MVC). The skin over the muscle belly of the vastus lateralis (VL), vastus medialis (VM), semitendionious (ST) and medial gastrocnemius (MG) in the dominant leg was abraded and cleaned prior to the application of bipolar silver/silver chloride surface electrodes in accordance to recommendations of the SENIAM project (78). A ground electrode placed on the tibial tuberosity. Leg dominance was determined by asking participants which leg they would kick a ball with if rolled to them. Standardized warm up was then performed, consisting of jumping jacks, body weight squats, quad and hamstring stretches and 5 submaximal CMJ and SJ attempts.

After completion of the warm up a 5 minute rest period was given prior MVC were collected. EMG signal was collected at 1000Hz (gain = 1000), using Noraxon Telemetry DTS 900 system (Scottsdale, AZ) through Vicon Nexus (Oxford, UK) software. Three trials of MVCs for each of the four muscles of interest were collected. MVCs were taken during knee extension, knee flexion and plantarflexion movements. Knee extension and flexion were performed on a padded weight bench with a leg extension attachment. Knee joint angle was set to ninety degrees. Subjects were asked to extend the leg as hard as possible into the leg extension attachment for five seconds followed by thirty seconds of rest for a total of three repetitions. Likewise, participants were asked to flex the leg into the pad as hard as possible for five seconds followed by thirty seconds of rest for a total of three repetitions. Plantarflexion MVCs were obtained by



asking the subjects to press their toes into the ground as hard as possible while in the standing as hard as they can for five seconds with thirty seconds of rest between three trials (147).

Both CMJ and SJ were performed using a wooden dowel (1.0 kg) placed across the shoulders in a high bar squat position. Subjects completed one set of three jumps at a self-selected foot position and to a self-selected depth. Prior to each jump subjects were instructed to jump as explosively as possible to achieve maximal height. Preceding each jump, subjects were instructed to remain as still as possible to allow for body mass to be determined and then used in the calculation of the phases of jump as suggested by Chavda et al. (29). The use of a 3, 2, 1, jump countdown was used for each trial.

Ground reaction force data was collected using a 600 x 400-mm force platform (Bertec Corp, Columbus, OH, USA). Force data was collected at 1000 Hz. Jump height from the force platform was calculated using the impulse – momentum method. The propulsive phase of each CMJ trial was identified using methods described by Chavda et al., (29) and McMahon et al., (104). Similar processing was adapted to SJ trials with the exclusion of an unweighting and braking phase. SJ analysis began by finding the mean of one second of weighting once at the self-selected depth and then identifying the first instance in which GRF was greater than 5 standard deviations (SD) above the mean of the one second weighting to signify the initiation of movement. From this point, methods were identical to those used in the analysis of the CMJ (29). Only the propulsive phase of the CMJ and SJ were used to determine mean muscle activity and the percentage of MVC during the jumping task. Additionally, reactive strength index modified was calculated as the ratio of jump height as determined from force platform calculations over the time to take off calculated as the time from movement initiation to the point of takeoff.

Ratings of perceived exertion (RPE) using the 0 – 10 OMNI-RES scale were taken at the end of each set of three jumps (46,95). Furthermore, the use a 13 centimeter visual analog scale (VAS) was also used to assess mood ratings with the labels of “No motivation at all” on the far left side and “Highest possible amount of motivation” on the far right side of the line. Subjects then marked the location on the line corresponding to the level of motivation perceived at that time. The line was measured from the left to the nearest 0.01 cm (84).

Raw EMG data was 4th order Butterworth bandpass filtered (20-250 Hz) and full wave rectification was performed. Mean MVC was defined by observing mean amplitude second by second over the five second trial and choosing the greatest one second of mean amplitude. The mean of the three MVC trials were then used in the analysis and for further calculations. Mean EMG amplitude during each jump trial was calculated as the mean amplitude across the entire propulsive phase of the each jump trial. The mean of the three trials for each jumping technique was then used in the analysis. During each jump trial, the mean propulsive EMG amplitude was normalized as a percentage against the EMG amplitude (100%) corresponding to the 1-s window of the peak MVC. Means values of the percentage of MVC across the three trials of the CMJ and SJ were then used in the analysis.

### **Statistical Analysis**

A within-subject repeated measures analysis of variance was used to assess the effect hydration on MVC, mean EMG amplitude during the propulsive phase and percentage of MVC, RPE and VAS ratings. Mauchly’s Test of sphericity was used test the assumption of sphericity for each variable. If the assumption was violated a Greenhouse – Geisser correction was used. Least significant difference post hoc analysis was used to determine where differences existed.

All statistics were run in SPSS version 25 (IBM, Chicago, IL). An a priori alpha level of 0.05 was used in all analysis. Effect sizes are presented as Cohen's  $d$  and interpreted using the criteria of trivial (0.0 – 0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), very large (2.0) and nearly perfect (4.0 or greater) as suggested by Hopkins (82). Effect sizes were first calculated as eta-squared values then converted to Cohen's  $d$  to make for comparisons to other investigations (36).

## RESULTS

All results are reported as mean  $\pm$  SD. Significant differences between USG measures were present ( $F_{2,38} = 126.088, p < 0.001, d = 5.15$ ) with significant differences seen between all conditions (Table 1). No differences were seen in any of the four muscles for MVC, propulsive mean muscle activity, and percentage of MVC (Table 1). No differences were seen between RSI<sub>m</sub> in either the CMJ or SJ (Table 1).

Significant differences were seen in the VAS ( $F_{2,38} = 3.31, p = 0.048, d = 0.86$ ) (Figure 1). Post hoc test revealed differences between hypohydrated and euhydrated conditions ( $p = 0.039$ ). Differences were present between conditions in RPE after the SJ ( $F_{2,38} = 4.39, p = 0.02, d = 0.98$ ) (Figure 2). Hypohydration was significantly higher than both the control and euhydrated conditions ( $p = 0.004$  and  $0.047$ , respectively). Similar findings were present in RPE after the CMJ ( $F_{2,38} = 4.527, p = 0.02, d = 1.00$ ), with differences between the hypohydrated and control conditions ( $p = 0.008$ ) and trending towards significant between hypohydration and euhydration ( $p = 0.07$ ) (Figure 2).

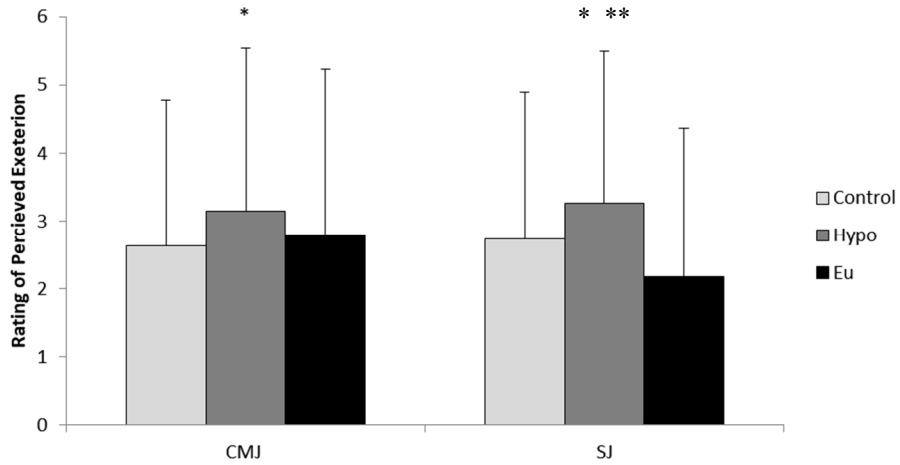


Figure 3: Comparison of RPE after each set of jumps across hydration conditions  
 \* Significantly different from euhydrated at  $p < 0.05$  level  
 \*\* Significantly different from control at  $p < 0.01$  level

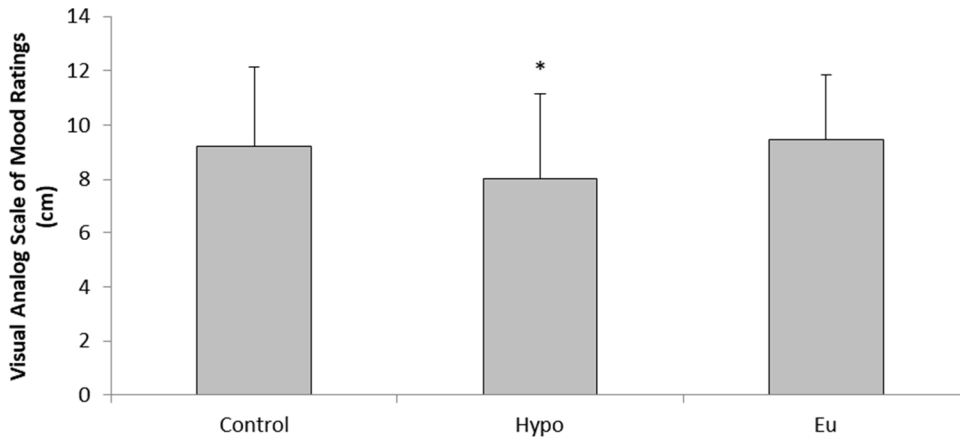


Figure 4: Mood Ratings across hydration conditions  
 \* Significantly different from euhydrated at  $p < 0.05$

Table 5: RSIm, EMG, and hydration variables across conditions (Mean  $\pm$  SD)

	CMJ			SJ		
	Control	Hypo	Eu	Control	Hypo	Eu
RSIm	0.75 $\pm$ 0.23	0.72 $\pm$ 0.21	0.73 $\pm$ 0.18	0.79 $\pm$ 0.32	0.74 $\pm$ 0.28	0.80 $\pm$ 0.24
MP Amplitude (mV)						
VL	1.253 $\pm$ 0.40	1.086 $\pm$ 0.37	1.139 $\pm$ 0.40	1.173 $\pm$ 0.38	1.077 $\pm$ 0.46	1.067 $\pm$ 0.27
VM	1.090 $\pm$ 0.44	1.090 $\pm$ 0.42	1.187 $\pm$ 0.39	1.074 $\pm$ 0.54	1.055 $\pm$ 0.37	1.082 $\pm$ 0.36
ST	0.270 $\pm$ 0.11	0.261 $\pm$ 0.09	0.278 $\pm$ 0.10	0.232 $\pm$ 0.10	0.235 $\pm$ 0.09	0.257 $\pm$ 0.10
MG	0.768 $\pm$ 0.36	0.755 $\pm$ 0.75	0.752 $\pm$ 0.20	0.675 $\pm$ 0.37	0.697 $\pm$ 0.39	0.636 $\pm$ 0.14
Normalized EMG Amplitude (%)						
VL	238.8 $\pm$ 122.4	234.9 $\pm$ 130.7	213.9 $\pm$ 116.1	179.3 $\pm$ 121.4	210.6 $\pm$ 134.6	183.4 $\pm$ 73.1
VM	218.2 $\pm$ 105.1	246.1 $\pm$ 81.6	206.1 $\pm$ 82.6	172.8 $\pm$ 131.3	208.2 $\pm$ 132.0	170.7 $\pm$ 63.3
ST	39.8 $\pm$ 19.3	38.7 $\pm$ 23.7	36.9 $\pm$ 22.3	26.3 $\pm$ 13.8	30.3 $\pm$ 14.6	29.4 $\pm$ 15.1
MG	113.2 $\pm$ 43.0	123.2 $\pm$ 31.8	124.4 $\pm$ 67.5	78.9 $\pm$ 48.3	100.4 $\pm$ 31.2	98.7 $\pm$ 55.7
MVC (mV)						
VL	0.656 $\pm$ 0.37	0.656 $\pm$ 0.38	0.591 $\pm$ 0.23			
VM	0.612 $\pm$ 0.42	0.541 $\pm$ 0.27	0.619 $\pm$ 0.19			
ST	0.790 $\pm$ 0.36	0.805 $\pm$ 0.42	0.915 $\pm$ 0.41			
MG	0.715 $\pm$ 0.29	0.638 $\pm$ 0.25	0.681 $\pm$ 0.25			
USG	1.018 $\pm$ 0.004*	1.023 $\pm$ 0.002*	1.007 $\pm$ 0.004*			

RSIm = Reactive strength index modified; MP = Mean propulsive; VL = vastus lateralis; VM = vastus medialis, ST = semitendinosus, MG = medial gastrocnemius; USG = urine specific gravity; CMJ = countermovement jump; SJ = Squat jump

\* significant difference at  $p < 0.001$

## **DISCUSSION**

The primary findings of this investigation showed there was no difference in mean muscle activity between hydration status during MVCs and during the propulsive phases of both the CMJ and SJ. Differences were seen however in both RPE and mood ratings across conditions. To the authors knowledge this is the first study to investigate the impact of hydration status on mean muscle activity and percentage of MVC during the vertical jumping task. Previous investigations that examined hydration status on muscle activity were collected during isometric and isokinetic contractions (54,77). The present investigation sought to see if similar findings would be present during an explosive movement such as the vertical jump. Though not commonly seen, it is proposed that a decrement of anaerobic performance seen in hypohydrated conditions is caused by a change in the neuromuscular system.

In the present investigation it can be seen that the dehydration protocol was successful as there were significant differences between all conditions (Table 1). The protocol used to induce hypohydration during this investigation sought to limit confounding factors from heat and exercise exposure. Cutoff values for hypo- and euhydration were different than the traditionally USG value of 1.020 (27). This was used to ensure that there would be differences between conditions. Though differences were seen in hydration status there were no differences seen in RSIm (Table 1). This is similar to previous investigations that examined hydration and the vertical jumping task (32,71,77,79). This would be expected as jump height is used in the calculation of RSIm and other investigations have shown no difference in jump height due to hypohydration. The advantage to using RSIm to jump height alone is that the factor of time, being that if it took longer to achieve a given jump height this would reduce the RSIm value. From the present data it seems that the CMJ height was not impacted by hydration status.

However, there was a small to moderate effect size ( $d = 0.59$ ) present in RSI<sub>m</sub> for the SJ. Similar results have been seen in SJ performance were a nonsignificant 4.7% reduction in jump height after heat induced hypohydration (71). Both the present investigation and that of Gutierrez et al. (71) showed that the CMJ was not impacted by hydration status while the SJ had a non-significant reduction. Thus, the countermovement itself during the CMJ may provide a mechanism to the attenuate the effects of hypohydration during the jumping task. Many previous investigations that have used the CMJ and jump height for the assessment of anaerobic power, could have found non-significant results that are a function of this attenuation mechanism of the countermovement.

EMG amplitude during MVC showed no differences between conditions. The present study supports the limited data between EMG amplitude during MVCs and hydration status (54,77). Furthermore, the present study shows that mean muscle activity during the concentric propulsive phase of the vertical jump is not impacted by hydration status. When mean amplitude was normalized against MVC, no differences were seen between conditions. A small to moderate effect was seen however in the VL ( $d = 0.43$ ) and VM ( $d = 0.53$ ) in the SJ. VL and VM percent of MVC was 27 and 38 percent higher respectively in the hypohydrated condition over the euhydrated. Similarly VL and VM percent of MVC was 31.3 and 35.4 percent higher in the hypohydrated over the control. These results show that in the hypohydrated condition the knee extensor musculature had work at a greater rate to produce the same outcome as measures by RSI<sub>m</sub>. Similar findings were seen in the CMJ with a small to moderate effect in the VL ( $d = 0.33$ ) and VM ( $d = 0.41$ ) with euhydration being the lowest value. It should be noted that during MVCs VM, ST, and MG all showed small to moderate effects ( $d=0.46, 0.41, 0.37$  respectively) of greater mean amplitude in the euhydrated condition. Thus, with near equal mean amplitude

during the SJ, a greater percentage would be seen. The slightly higher MVC amplitude in the euhydrated condition agrees with Vallier et al. (136) that showed no significant differences between conditions of hydration, but lower muscle activity during MVC in the fluid restricted condition in the VL. Contradicting findings were found by Evetovich et al. (54) where near identical amplitude was seen in isometric conditions and greater amplitude during isokinetic conditions in the biceps brachii.

RPE was taken to assess the impact that hydration status had in completing both the CMJ and SJ. Significant differences were seen in CMJ with higher values seen in the hypohydrated condition over the control condition and trending towards significance in with regard to the euhydrated. A similar pattern was seen in the SJ as hypohydration RPE was significantly greater than both the other conditions. These findings support those of Vallier et al. (136) that used RPE values during prolonged cycling with fluid restriction that over time higher RPE was seen to accomplish the same outcome of cycling at ~60%  $\text{VO}_2$  max for 3 hours. As endurance exercise has other factors related to hydration such as increase in heart rate and core temperature that are not seen in anaerobic exercise agreement between studies may be limited. Davis et al. (46) included RPE measures when examining intermittent sprinting and hydration state and found that when subject were hypohydrated, they expressed greater RPE values over euhydration after each bout of sprints. The results of the present investigation support the findings of previous investigations while adding an element that the jumping task that was performed is more anaerobic in nature than either of the previous investigations using RPE measures.

VAS measures of mood ratings showed significant differences between hypohydration and euhydration. These findings support the findings of Jones et al (84) that used a similar scale during upper and lower body wingate anaerobic testing. While they did not find significant



differences between conditions, a 23.0% decrease was seen between conditions. Lower muscle activity during the MVC could be explained by these findings, that subjects were less motivated during the hypohydration. The results of higher RPE scores in both jumps and the decreased mood rating during hypohydrated sessions support the findings of greater percentage of MVC. The results of this study show that while completing both the SJ and CMJ to a similar outcome it was perceived as more difficult task as well as shown to take a greater muscle activity.

It should also be noted that differences were not seen between RPE and VAS measures in the control and euhydrated conditions. Though the euhydrated and control conditions were shown to represent different levels of hydration ( $p < 0.001$ ), both would be classified as euhydrated using the traditional criterion value of USG  $< 1.020$  as a euhydrated (27). This shows that a potential dose response does not exist in regard to RPE and VAS measures. Similar findings were shown in faster isokinetic contraction velocities which would have been more similar to the contraction velocities seen in the present study (77). This is the first investigation to the author's knowledge that examined RPE and mood rating concurrently with anaerobic performance as it relates to hydration status. Thus, future investigations evaluate should include RPE or mood ratings along with task performance when examining the impact of hydration status.

Limitations of this investigation include that torque or force measures were not taken concurrently during MVC. This could help in providing further insight as to how hydration status could impact isometric force production, though previous investigations show that force remains unaffected during isometric contractions. Additionally, the subjects used were recreationally trained males and results may differ for different levels of athletes as they may be more accustomed to the CMJ and SJ from training and sport participation. However, the results from this investigation are similar to those in athletic populations with regard to RSI<sub>m</sub> (50).

## **PRACTICAL APPLICATION**

This investigation demonstrated that while the outcome of two of the more popular methods used in the assessment of athletes may not be impacted by hydration state, that the manner in which that outcome was achieved potentially could be different. As well it should be noted that when conducting assessments into the readiness of athletes that the inclusion of a simple hydration measure may provide practitioners and sport scientist additional information about the results of their assessments and the current state of the athlete.

## **CONCLUSIONS**

This study found supporting evidence that no differences were seen in muscle activation during MVC as well as during the movement itself. However, a small to moderate effect was seen in the percentage of MVC that corresponds to higher RPE and lower mood ratings when hypohydrated. These findings are important to have a better understanding of how hydration impacts anaerobic performance measures such as the vertical jumping task, in addition to how hydration impacts tools used the assessment of athletes to train and compete.

**CHAPTER V**  
**MANUSCRIPT III**

## **Comparison of Squat and Countermovement Jumps**

To be submitted to the Journal of Strength and Conditioning Research

## INTRODUCTION

Monitoring and testing athletic performance has become a critical piece in the training of athletic populations across various levels of competition. An important aspect to both monitoring and testing athletes is to limit the amount of additional fatigue that can be caused by the testing measure itself. This has led to the use of the countermovement (CMJ) and squat (SJ) jumps as both can be implemented with relative ease into training programs while limiting the amount of additional fatigue to the athlete. While the goal of both movements is similar in that one tries to jump to a maximal height, differences in the movement themselves typically cause a difference in the outcome of the movement. During the CMJ the athlete begins the task by starting in a standing position before descending into a semi squat, which is immediately followed by an upward motion that leads to takeoff from the ground. Conversely, the SJ begins from the same upright standing position and descent into a semi squat position, however this semi squat position is held for 3 to 5 seconds typically before performing an upward movement to achieve takeoff from the ground. When the same individual performs both movements the CMJ will almost always outperform the SJ when time-dependent factors are excluded (13,15,89,102). This can be seen by the greater jump heights in the CMJ over the SJ.

Several possible explanations have been used throughout the literature to explain as to why CMJ performance is greater than that of SJ. Traditional views suggest that the greater performance in the CMJ is attributed to a greater the performance-enhancing effect of the stretch-shortening cycle (81). The performance-enhancing effect of the stretch-shortening cycle however, has been attributed to several different mechanisms. Several studies have shown that similar muscle activation is seen in both the CMJ and SJ with the use of electromyography (EMG) in the knee extensor musculature (15,20,75). Thus, Bosco et al. (20) suggested that with

similar activation patterns the enhanced performance in the CMJ was primarily attributed to effective recoil of the elastic energy in the muscle during the stretch-shortening cycle. Similar results were seen by Bobbert et al. (15) in that no differences were seen in muscle activity of the lower body again suggesting that the use of elastic energy produced through the countermovement as the mechanism to greater performance. However, the authors did see that greater values of force at the beginning of the propulsive phase and greater velocity of the center of mass at the point takeoff. These results showed that enhanced muscle activity again was not the primary mechanism for greater jump height in the CMJ and concluded that the amount of work a muscle could perform with the addition of a countermovement was greater than without the countermovement (15). This work being that a greater force was present at the initiation of the propulsive phase.

While force production is important to the vertical jumping task, it has been seen that peak values of forces can be similar between jumping techniques (59). This leads to simply investigating the velocity at the point of take-off, which is critical to the achievement of jump height. The greater that the velocity is at takeoff, the longer it would take for the constant negative acceleration of gravity to bring you to a stop and return you to the ground. Thus, achieving a longer time in the air and leading to a greater jump height. Additionally, it has been shown that a reduction in peak force can occur over the course of a competitive season, while maintaining jump height in the CMJ (132). Thus, differences in the SJ and CMJ jump height would not be attributed to force production but rather the velocity of the movement.

In previous studies that propose mechanisms to explain the difference in SJ and CMJ performance, investigators used subjects that were familiar with the techniques associated with jumping to maximal heights as well as other explosive lower body movements (15,75). This is

important to note as the SJ could potentially be a novel jumping technique that they would have less experience with causing a difference in performance even if controlling for other aspects (arm swing, depth of countermovement, etc). Thus, using athletes and populations that do not rely on jump height to perform at high level could provide greater insight into the differences that exist between the jumping techniques.

Thus, the primary purpose of this investigation was to examine differences in the electromyography, kinetics, and kinematics of the SJ and CMJ in a cohort of recreationally trained individuals.

## **METHODS**

### **Experimental Approach to the Problem**

A counterbalanced within-subject design was used to identify differences in electromyography during the concentric portion of both CMJ and SJ. Participants visited the laboratory for a total of two sessions, one familiarization session and one experimental session that were separated by a minimum of 24 hours. During the first visit participants were screened for exclusionary criteria and familiarized with test protocols for the CMJ and SJ as well as maximal voluntary contractions (MVC).

### **Subjects**

Twenty-two ( $n = 22$ ) recreationally trained males (height  $180.07 \pm 8.48$  cm, body mass  $84.51 \pm 12.63$  kg) between the age of 18 and 35 (age  $23.61 \pm 2.64$  years) participated in this investigation. All subjects were physically active for the 6 months preceding data collection and were deemed to be free of injury and cleared for physical activity by the physical activity

readiness questionnaire (PAR-Q). Informed consent approved from the University Institutional Review Board was obtained

## **Procedures**

Upon arrival to the experimental session subjects were prepped for MVCs. The skin over the muscle belly of the vastus lateralis (VL), vastus medialis (VM), semitendionious (ST) and medial gastrocnemius (MG) in the dominant leg was abraded and cleaned prior to the application of bipolar silver/silver chloride surface electrodes with a ground electrode placed on the tibial tuberosity. Leg dominance was determined by asking subjects they would kick a ball with if rolled to them. Standardized warm up was then performed, consisting of jumping jacks, body weight squats, quad and hamstring stretches and 5 submaximal CMJ and SJ attempts each.

After completion of the warm up a 5 minute rest period was given prior MVC being collected. EMG was collected at 1000Hz using Noraxon Telemetry DTS 900 system (Scottsdale, AZ) through Vicon Nexus (Oxford, UK) software. Three trials of MVCs for each of the four muscles of interest were collected. MVCs of the knee extension (VL and VM), knee flexion (ST) and plantarflexion (MG) movements were performed. Knee extension and flexion were performed on a padded weight bench with a leg extension attachment. Knee joint angle was set to ninety degrees. Subjects were asked to kick into the pad on the attachment hard as possible for five seconds followed by thirty seconds of recovery. This was then repeated for a total of three repetitions. Likewise, participants were asked to pull their leg into the pad as hard as possible for five seconds followed by thirty seconds of recovery for a total of three repetitions. Plantarflexion MVCs were obtained by asking the subjects to press their toes into the ground as hard as possible



while in a standing position with minimal knee flexion for five seconds with thirty seconds of recovery between trials for a total of three trials (147).

During both the CMJ and SJ a wooden dowel (1.0 kg) was placed across the shoulders in a high bar squat position. Participants completed one set of three jumps at a self-selected foot position and to a self-selected depth. They were instructed to jump as explosively as possible to achieve maximal height (3). Participants were also instructed to maintain contact between the wooden dowel and the upper back at all times throughout the movement. The use of a 3, 2, 1, jump countdown was used for each trial. If a countermovement was visual detected during the SJ the trial was repeated.

Ground reaction forces were also collected using a 600 x 400-mm force platform (Bertec Corp, Columbus, OH, USA). Force data was collected at 1000 Hz. Ground reaction data was used in the identification of the propulsive phase of the CMJ using methods recommended by Chavda et al.(29) and McMahon et al. (104). EMG and ground reaction force data was synchronized through the Vicon Nexus software. Using similar methods to that of the CMJ, SJ was analyzed by first finding the mean of one second of weighting once at the self-selected depth and then identifying the first instance in which GRF was greater than 5 standard deviations (SD) above the mean of the one second weighting to signify the initiation of movement. From this point to the instance of take-off was defined as the propulsive phase of the SJ. Only the propulsive phases of each jump technique were used in the analysis.

Raw EMG data was 4<sup>th</sup> order butterworth bandpass filtered (20-250 Hz) and full wave rectification was performed prior to the data analysis. Mean muscle activity of the MVC was calculated as the greatest one second of mean amplitude during the contraction. Mean muscle

activity during each jump was calculated as the mean rectified signal across the entire propulsive phase. Percentage of MVC was calculated as the propulsive mean muscle activity for each trial over the mean MVC muscle activity. Mean values across the three trials of the CMJ and SJ were then used in the analysis.

After determination of the end of the braking phase and takeoff point the peak and mean force, velocity, and power for the entire propulsive phase was calculated. Using double differentiation of ground reaction data, velocity was calculated for each time point. Power was then determined as the product of force and velocity. Additionally, jump height was then calculated using the impulse-momentum method.

### **Statistical Analysis**

Paired sample t-tests were used to analyze differences between CMJ and SJ for all variables of interest. Shapiro-Wilk tests of normality were conducted on each variable. All statistical analyses were performed in SPSS version 25 (IBM, Chicago, IL). An a priori alpha level of 0.05 was used in all analysis. Effect sizes are presented as Cohen's *d* and interpreted using the criteria of trivial (0.0 – 0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), very large (2.0) and nearly perfect (4.0 or greater) (82). Correlation coefficients are interpreted as trivial (0.00 – 0.1), small (0.1 – 0.3), moderate (0.3 – 0.5), large (0.5 – 0.7), very large (0.7 – 0.9) and nearly perfect (0.9 – 1.0) as suggested by Hopkins (82).

### **RESULTS**

Significant differences were found in mean muscle activity in the ST ( $t(21) = 2.051, p = 0.02, d = 0.54$ ) (Figure 1). No significant differences were seen in the VL, VM, and MG with regard to mean muscle activity (Figure 1). Significant differences were seen in with respect to percentage

of MVC between CMJ and SJ in the ST ( $t(21) = 2.89, p = 0.009, d = 0.62$ ); and MG ( $t(21) = 2.40, p = 0.026, d = 0.51$ ) (Figure 2). No differences were seen in the VL and VM in regard to percentage of MVC.

Significant differences were seen in jump height between CMJ and SJ ( $t(21) = 2.86, p = 0.009, d = 0.61$ ) (Table 1). Significantly greater values were seen in SJ over CMJ in regards to mean force ( $t(21) = 9.75, p < 0.001, d = 2.08$ ) and mean power ( $t(21) = 4.73, p < 0.001, d = 1.01$ ) (Table 1). Conversely, significantly greater values were seen in peak and mean velocity in the CMJ over SJ ( $t(21) = 2.58, p = 0.018, d = 0.55$  and  $t(21) = 14.72, p < 0.000, d = 3.14$ , respectively) (Table 1). No significant differences were seen in peak force and peak power.

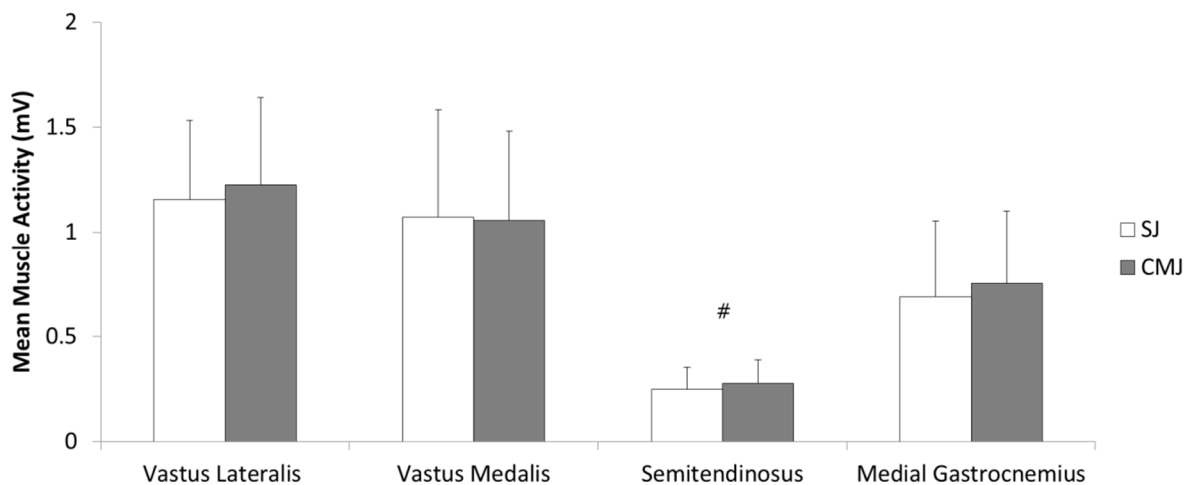


Figure 5: Mean muscle activity during the propulsive phase of the squat and countermovement jumps.

# Significant difference between jumps at  $p < 0.05$  level

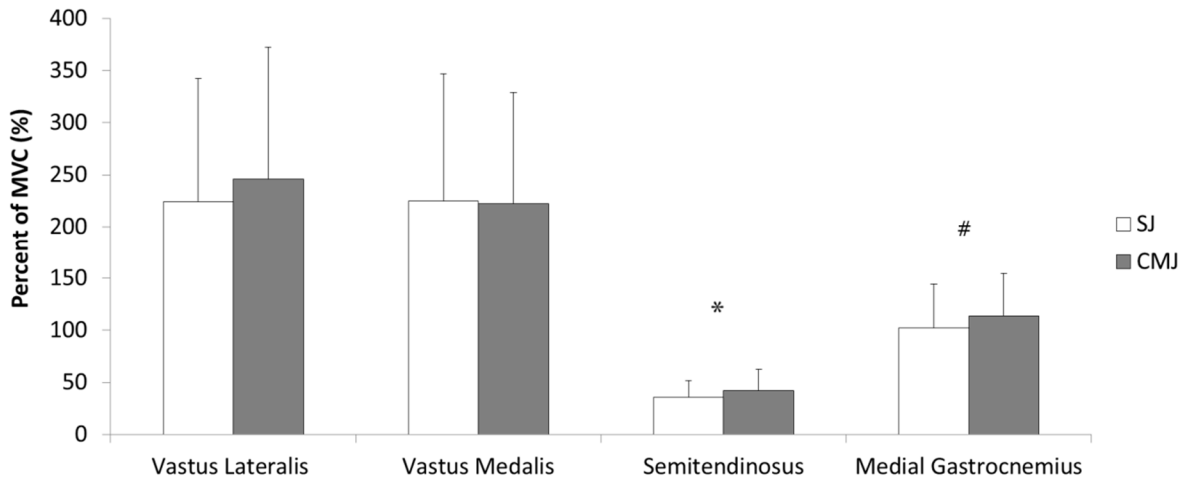


Figure 6: Percentage of MVC during the propulsive phase of the squat and countermovement jumps

# Significant difference between jumps at  $p < 0.05$

\* Significant difference between jumps at  $p < 0.01$

Table 6: Comparison of Squat and Countermovement Jumps (mean  $\pm$  SD)

	SJ	CMJ	P Value	Effect Size
Peak Force (N)	2103.19 $\pm$ 378.04	2069.82 $\pm$ 258.59	0.66	0.10
Mean Force (N)*	1560.37 $\pm$ 210.18	1186.08 $\pm$ 132.69	< 0.001	2.08
Peak Velocity (m/s)*	2.70 $\pm$ 0.17	2.78 $\pm$ 0.23	0.018	0.55
Mean Velocity (m/s)*	1.25 $\pm$ 0.10	1.71 $\pm$ 0.18	< 0.001	3.14
Peak Power (w)	4659.32 $\pm$ 673.96	4627.89 $\pm$ 657.25	0.76	0.07
Mean Power (w)*	1973.31 $\pm$ 310.64	1705.39 $\pm$ 195.89	< 0.001	1.01
Jump Height (cm)*	33.51 $\pm$ 0.05	35.66 $\pm$ 0.06	0.009	0.61

SJ = Squat jump; CMJ = Countermovement Jump

\* = Significant differences between jumps

## DISCUSSION

The main findings of this investigation include that the similar muscle activity occurs in the knee extensor musculature during both the SJ and CMJ and differences in peak and mean velocity during the propulsive phase show the greatest relationship to performance differences in the two jumping techniques in recreationally trained males. The results of this investigation also revealed that in recreationally trained males that have a varying level of exposure to jumping and/or jump training, showed no differences in peak force and peak power between the jumping strategies but did find that mean force and power across the entire propulsive phase was greater during the SJ.

The findings that differences were not present in mean muscle activity of knee extensors in the propulsive phase of both jumps coincides with previous findings investigating muscle activity as a potential mechanism for the difference in jumping performance (15,20,75). Though in the present study, VL mean muscle activity was not significantly different between jumps, ( $p = 0.076$ ) a small to moderate effect size was present. These results and the percentage of MVC in the VL show a similar pattern to previous investigations that examined muscle activity in that a non-significant increase knee extensor activity in the CMJ (75). The difference between the present study and that completed by Hakkinen et al (75) was that SJ was used as the normalization method rather than MVC. It has been reported that normalization techniques used for muscle activity during the vertical jumping task is difficult as the MVC values are joint angle specific and thus percentages greater than 100 percent are common.

However, greater muscle activity was seen in the ST during the CMJ. This is in contrast to the previous findings that showed no difference in knee flexor muscle activity (15,115). Each of

the previous studies had contrasting findings as no differences were seen by Bobbert et al. (15) and greater amplitude were observed in the SJ over the CMJ by Padulo et al. (115). The differing results from the current investigation can come from observation of different musculature, as both of the previous investigations examined the biceps femoris. When comparing percentage of MVC to the Padulo et al. (115) similar levels were seen in the SJ while large differences were seen in the CMJ (42% vs 25%). The greater muscle activity in the ST may be attributed to coordination differences between jumping techniques as well as antagonist activity to offset slightly higher agonist activity of the knee extensors. MG mean muscle activity through not significantly different showed a small to moderate effect size. This is similar to other investigations in which the muscle activity of the plantar flexors was measured in both CMJ and SJ (94). However, previous investigations have shown no differences in plantar flexor muscle activity (15,59,87) This could explained by differences in populations as Bobbert et al (15) a sample of 3 volleyball athletes that were accustomed to jumping were the current population was not. The difference in percentage activation would coincide with the differences seen in mean muscle activity of the MG as both the SJ and CMJ were divided by the same MVC value. The percentage of activation was included in the investigation as a means to make comparisons to other literature as both mean and percentage are reported. The results in the current investigation in regard to percentage of MVC are different from those of Kawakami et al. (87) were no difference was seen between jumping techniques. This in part may be due to methodological differences obtaining MVC values and jumping conditions. With regard to all muscle activity differences seen in the present study the impact on jump performance would to be small to negligible as no differences were seen in the knee extensors. The lack of consistency of muscle activity in both jumping techniques lends itself to having little impact. This is consist to other

investigations conclusions on the role of muscle activity during the CMJ and SJ in explaining differences seen in jump height performance (15,20,75,81).

Ground reaction forces recording during both jumping techniques showed no differences in peak force during the propulsive phase of the jump. This is similar to the results that were reported by Finni et al. (59) where similar force was seen between jumps. The greater mean force during the propulsive phase of the SJ could be explained by the longer propulsive phase time in the SJ. If peak values were similar than a longer period of time of increasing force to reach that peak value could increase the mean value across the entire phase. The greater mean power would also be explained from a similar manner in that power was calculated as the product of force and velocity. Additionally, many of the subjects showed bimodal propulsive phase force time histories in the CMJ. This reduction in force between the first and second peaks could have contributed to the lower mean force and power values in the CMJ. In some cases the second peak was at a lower value than that of the first peak, thus a reduction in force was seen throughout the propulsive phase. The shape of the force-time curves during the propulsive phase may have been in part to the experience level the participants had with the jumping task where individuals were creating large forces to bring the countermovement to a stop before changing directions of the center of mass. This is important to the understanding of the results in the present investigation and the translation of the results to other populations where the jumping is not a critical part of success in the sport. As both the CMJ and SJ are commonly used as assessments of lower body power, translation to on-field performance can be limited. Donahue et al. (49) showed no significant relationship between pitching velocity in professional baseball pitchers and CMJ performance. This does not discredit the use of the CMJ as a measurement tool in populations where jumping performance is not a critical part to on-field success, but shows that the use of

such tools should be done with caution. Thus, further investigations should examine the variables used with such populations in determining the translation to on-field success. This is important to acknowledge in the present study as many of the previous studies investigating differences in CMJ and SJ have used populations that rely on the stretch-shortening or explosive lower body movements to have greater success (15,20,75).

Significant differences in peak and mean velocity were seen between the CMJ and SJ. These findings show that simply the ability to accelerate one's own mass at a greater velocity can help in explaining the differences in jump height that was seen in the present investigation. The difference between peak velocity of the two jumps is similar to that of the Bobbert et al. (15) where the CMJ had greater velocity than three separate SJ starting positions.

The data presented in this study shows similar levels of peak propulsive force and power were present in the CMJ and SJ with difference still existing in jump height and greater mean values in the SJ to that of the CMJ. While these findings are in contrast to other studies it may provide some insight to the importance to movement velocity in during jumping. Van Hooren and Zolotarjova (81) recently reviewed the underlying mechanisms to the difference in CMJ and SJ performance and proposed that a greater uptake of muscle slack and the buildup of high stimulation during the countermovement was the primary mechanism for greater performance. While it is important to have an understanding as to the mechanism to which greater jump height is achieved and it also important to note which variable is this mechanism impacting. It was seen in this investigation as well as others that muscle activity differences were not implicated in differences seen between CMJ and SJ performance. It was also seen that peak levels of force and power were similar between jumps and that mean force and power was greater during the SJ. Based on the findings of this investigation it appears that any proposed mechanism as to the



increase in jump height in the CMJ over the SJ is centered around peak velocity of the movement. Peak velocity was the only variable assessed in which significantly higher values were seen in the CMJ over the SJ that coincided with the increase in CMJ jump height. The addition of a countermovement to the jumping task is similar to other sporting actions (ie overhand throwing) in which a countermovement is present, and a greater peak velocity is achieved. Therefore, further investigations should examine any proposed mechanism and the movement velocity concurrently during the CMJ and SJ to determine the impact on jump height. Future investigations, similar to the present study should also examine if populations where jumping ability plays a vital role in successful sport performance shows similar findings in regard to peak values in force, velocity and power.

## **PRACTICAL APPLICATION**

Similar to other sporting movements where the stretch-shortening cycle is present, the end result of the movement is an increase in the peak velocity that achieved. This increase in velocity is critical to achieve a greater height in both the CMJ and SJ. While there have been many proposed mechanisms to why differences are seen between the CMJ and SJ the variable that is seems to be influenced the most is the peak velocity as it represents a nearly perfect relationship with jump height.

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### **PUBLISHED MANUSCRIPTS**

1. Hill, C, Wilson, SJ, Mouser, JG, **Donahue, PT**, and Chander, H. Motor Adaption During Repeated Motor Control Testing: Attenuated Muscle Activation Without Changes in Response Latencies. *Journal of Electromyography and Kinesiology*. 41: 96 -102, 2018
2. **Donahue PT**, Beiser EJ, Wilson, SJ, Hill, CM and Garner JC. The relationship between measures of lower body power and pitching velocity in professional pitchers. *Journal of Trainology*. 7: 24-27, 2018

### **MANUSCRIPTS IN REVIEW**

1. Wilson SJ, **Donahue PT**, Williams CC, Hill CM, Chander, H, Garner JC & Waddell, D. Is It All in Your Head? The Possible Role of Corticospinal Demand in Slip Recovery Responses. *Journal of Neurophysiology*. (In Review)
2. Wilson SJ, **Donahue PT**, Williams CC, Hill CM, Waddell DE, Bentley JP, Bass, MA, & Garner JC. Postural Control Measures May Provide Insight into The Importance Of Sensory Integration And Motor Control Strategies Used During Slip Recovery. *Gait and Posture*. (In Review)
3. Wilson SJ, **Donahue PT**, Williams CC, Hill CM, Waddell DE, Loenneke JP, Wade C, & Garner JC. Lower Extremity Corrective Events During The Slip Recovery Response Between Slip-Induced Falls And Recoveries. *Journal of Biomechanics* (In Review)
4. Williams CC, **Donahue PT**, Wilson SJ, Mouser JG, Hill CM, Luginland LA, Gdovin, JR Wade C, and Garner JG. Examining Changes in Bat Swing Kinematics In Different Areas Of The Strike Zone In Collegiate Baseball Players. *Journal of Strength and Conditioning Research* (In Review)

## MANUSCRIPTS IN PREPARATION

1. **Donahue PT**, Jackson PM, Studzinski DJ, Wilson SJ, Hill CM, Whitehead J, Coleman L, & Garner JC. Relationship Between Strength, Jumping, And Sprint Performance in Collegiate Football Athletes. (Manuscript preparation in progress)
2. **Donahue PT**, Jackson PM, Studzinski DJ, Whitehead J, Coleman L, & Garner JC. Prediction of 1RM Back Squat Performance in Division I Football Athletes. (Data Analysis in progress).
3. **Donahue PT**, Wilson SJ, Williams CC, Hill CM & Garner JC. Comparison of Anthropometrics, Lower Body and Rotational Power Amongst Professional Baseball Pitchers. (Manuscript preparation in progress)

## PEER REVIEWED ABSTRACTS

1. Wilson SJ, **Donahue PT**, Hill CM, Williams CC, Simpson JD, Chander H, Wade C, Wilhoite SV, Neitz K, Haynes, A, Pascal J, Lewis K, Crawford A, Munkasy B, Li L, Garner JC, & Waddell DE. Novel Evidence of Cortical Control in Severe Slip Responses. American College of Sports Medicine (ACSM) Annual Meeting, Orlando, FL. May 28 – June 1, 2019.
2. Crawford A, **Donahue PT**, Hill CM, Williams CC, Simpson JD, Chander H, Wade C, Wilhoite SV, Neitz K, Pascal J, Haynes A, Lewis K, Johnson A, Munkasy B, Li L, Garner JC, Waddell DE & Wilson SJ. Examination of the Influence of Lead Leg Recovery Mechanics on Slip Induced Outcomes. American College of Sports Medicine (ACSM) Annual Meeting, Orlando, FL. May 28 – June 1, 2019.
3. Haynes A, **Donahue PT**, Hill CM, Williams CC, Simpson JD, Chander H, Wade C, Johnson A, Wilsoite SV, Neitz K, Lewis K, Pascal J, Crawford, Munkasy B, Li L, Garner JC, Waddell DE, & Wilson SJ. The Effects of Postural Control Measures on Induced Slip Outcomes. American College of Sports Medicine (ACSM) Annual Meeting, Orlando, FL. May 28 – June 1, 2019.
4. Pascal J, **Donahue PT**, Hill CM, Williams CC, Simpson JD, Chander H, Wade C, Lewis K, Wilhoite SV, Neitz K, Haynes A, Johnson A, Crawford A, Munkasy B, Li L, Garner JC, Waddell DE & Wilson SJ. Lead Leg Corrective Responses to Varying Slip Severity. American College of Sports Medicine (ACSM) Annual Meeting, Orlando, FL. May 28 – June 1, 2019.
5. **Donahue PT**, Hill CM, Wilson, SJ, Williams, CC, Jackson, PM, and Garner JC. Comparison of Positional Differences in 1RM Squat Performance Using Differing Normalization Methods in Football Athletes. *Southeast American College of Sports Medicine Annual Conference*, Greenville, SC, February 14<sup>th</sup>-16<sup>th</sup> 2019.



6. Wilson, SJ, **Donahue PT**, Hill CM, Williams CC, Simpson JD, Siekirk N, Garner JC. & Waddell DE. Novel Evidence of Cortical Control in Severe Slip Responses. *Southeast American College of Sports Medicine Annual Conference*, Greenville, SC, February 14<sup>th</sup>-16<sup>th</sup> 2019.
7. Williams CC, **Donahue PT**, Wilson SJ, Mouser JG, Hill CM, Luginsland LA, Wade C, and Garner JG. Changes in Bat Swing Kinematics Across the Strike Zone in Collegiate Baseball Players. *Southeast American College of Sports Medicine Annual Conference*, Greenville, SC, February 14<sup>th</sup>-16<sup>th</sup> 2019.
8. Hill CM, Wilson SJ, **Donahue PT**, Mouser JG, Chander H. Effect of Repeated Motor Control Testing on Time to Peak Lower Extremity Muscle Activity. SEASCM Annual Meeting, Greenville, SC February 14-16, 2019.
9. **Donahue PT**, Hill C, Walker, K Wilson S, Wade C. Variations in Kinematics During Lumbar Flexion/Extension Bending: A Comparison of Bending Techniques. Congress of Neurological Surgeons 2018 Annual Meeting, Houston, TX.
10. Wilson SJ, Garner JC, **Donahue PT**, Williams CC, Hill CM, Waddell DE. The Possible Role of Corticospinal Pathway Demand in Slip Recovery Responses. *50<sup>th</sup> Biomedical Engineering Society (BMES)*, Atlanta, GA, USA. October 17-20, 2018.
11. Hill CM, Wilson SJ, Mouser JG, **Donahue PT**, Williams CC, Chander H. Repeated Motor Control Testing Decreases Co-Contraction Index in Healthy Young Adults. *42<sup>nd</sup> American Society of Biomechanics (ASB) Annual Meeting*, Rochester, MN, USA. August 8-11 2018.
12. **Donahue PT**, Jackson PM, Wilson SJ, Williams CC, Hill CM, Studzinski DJ, Whitehead J, Coleman L, & Garner JC. Positional Differences in Countermovement Jump Velocity in Division I Football Athletes. NSCA Annual Meeting, Indianapolis, IN. July 12-14. National Strength and Conditioning Association.
13. **Donahue PT**, Beiser E, Wilson SJ, Williams CC, Hill CM, & Garner JC. Relationship of Countermovement Vertical Jump Performance and Pitching Velocity. NSCA Annual Meeting, Indianapolis, IN. July 12-14. National Strength and Conditioning Association.
14. Hill CM, Wilson SJ, Mouser JG, Williams CC, Luginsland LA, **Donahue PT**, Chander H. Impact Of Repeated Balance Perturbations On Lower Extremity Mean Muscle Activity. Mid-South Biomechanics Conference, Memphis TN. February 22-23 2018.
15. **Donahue PT**, Wilson SJ, Williams CC, Hill CM, Luginsland LA, and Garner JC. Positional Differences In Peak Power During Countermovement Vertical Jump In Professional Baseball Pitchers. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Chattanooga, TN. February 15-17 2018.

16. Hill CM, Wilson SJ, Mouser JG, Williams CC, Luginsland LA, **Donahue PT**, Chander H. Impact Of Repeated Balance Perturbations On Lower Extremity Mean Muscle Activity. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Chattanooga, TN. February 15-17 2018.
17. Wilson SJ, Hill CM, Mouser JG, Williams CC, Luginsland LA, **Donahue PT**, Garner JC, Chander H. Can Postural Responses Be Learned? Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Chattanooga, TN. February 15-17 2018
18. Garner JC, Hill CM, Wilson SJ, Mouser JG, Williams CC, Luginsland LA, **Donahue PT**, Chander H. Influence of Repeated Motor Control Tests on Proximal Lower Extremity Musculature Activation. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Chattanooga, TN. February 15-17 2018
19. Luginsland LA, Williams CC, Gdovin JR, Wilson SJ, **Donahue PT**, Hill CM, Eason JD, Yarbrough AL, Wade C, Garner JC. Changes in Bat Angle at Maximal Velocity in Collegiate Softball Players. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Chattanooga, TN. February 15-17 2018.
20. Williams, CC; Gdovin JR; Wilson SJ; Hill CM; **Donahue, PT**; Luginsland LA; Eason JD; Yarbrough AL; Wade C; Garner JC. Examining changes in bat angle at ball contact in collegiate softball players over a fall softball season. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Chattanooga, Tennessee February 15-17<sup>th</sup>.
21. **Donahue PT**, Jackson, PM, Wilson SJ, Gdovin JR, Williams CC, Luginsland LA, Hill CM, Studzinski DL, Guarascio JJ, Garner JC. Effect of Offseason Training on Countermovement Jump Velocity in Division I Football Athletes. NSCA Annual Meeting, Las Vegas, NV. July 12-15. National Strength and Conditioning Association.
22. Wilson SJ, Gdovin JR, Williams CC, Eason JD, Luginsland LA, Hill CM, **Donahue PT**, Hoke EL, Chander H, Garner JC. More Than a Foot Wedge – Golf Footwear and Postural Control. *NSCA Annual Meeting*, Las Vegas, NV. July 12-15. National Strength and Conditioning Association.
23. Hill CM, Williams CC, Gdovin JR, Wilson SJ, Eason JD, Hoke EL, **Donahue PT**, Wade C, Garner JC. The effects of various weighted implements on perception and bat angle in collegiate baseball players. NSCA Annual Meeting, Las Vegas, NV. July 12-15. National Strength and Conditioning Association
24. EL. Hoke, SJ. Wilson, JR. Gdovin, CC. Williams, JD. Eason, LA. Luginsland, CM. Hill, **PT. Donahue**, H. Chander, C.Wade, M. Green, and JC. Garner. Acute Effects Of Golf Specific Footwear On Bilateral Balance. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Greenville, SC. February 16-18 2017.

25. Gdovin JR, Wilson SJ, Williams CC, Eason JD, Hoke EL, Luginsland LA, Hill CM, **Donahue PT**, Davis RE, Chander H, Wade C, Garner JC. The Acute Effects Of Golf Specific Footwear On Reaction Time Latencies. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Greenville, SC. February 16-18 2017.
26. Eason JD, Wilson SJ, Gdovin JR, Williams CC, Hoke EL, Luginsland LA, Hill CM, **Donahue PT**, Chander H, Wade C, Garner JC. The effects of golf shoe type on balance equilibrium scores. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Greenville, SC. February 16-18 2017
27. Wilson SJ, Gdovin JR, Williams CC, Eason JD, Hoke EL, Luginsland LA, Hill CM, **Donahue PT**, Davis RE, Chander H, Wade C, Garner JC. The Effects of Golf Specific Footwear on Human Balance. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Greenville, SC. February 16-18 2017.
28. Williams CC, Wilson SJ, Gdovin JR, Eason JD, Hoke EL, Luginsland LA, Hill CM, **Donahue PT**, Davis RE, Chander H, Wade C, Garner JC. The Influence Of Golf Specific Footwear On Whole Body Reaction Times. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Greenville, SC. February 16-18.
29. Luginsland LA, Wilson SJ, Gdovin JR, Williams CC, Hoke EL, Eason JD, Hill CM, **Donahue PT**, Chander H, Wade C, Garner JC. The Acute Influence Of Golf Specific Footwear On Equilibrium Scores. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Greenville, SC. February 16-18 2017.
30. **Donahue, T**, Szymanski, D, Stover, B, Elumalai, A, Parks, J. Effect of hip internal rotation training on range of motion and performance variables in male collegiate golfers. Presented at the National Strength and Conditioning Association National Conference, Las Vegas, NV., 2013.
31. Szymanski, D, **Donahue, PT**, Tolbert, W, Stover, B, Elumalai, A, Greenwood, M. Effect of weighted implement training on bat velocity of high school baseball players. A pilot study. Presented at the National Strength and Conditioning Association National Conference, Las Vegas, NV., 2013.
32. Szymanski, D, **Donahue, PT**, Stover, B, Boyce, D, Africa, L, Greenwood, M., Beam, J. Effect of novel warm-up devices on bat velocity and perception of heaviness and speed of swing of collegiate baseball players. Presented at the National Strength and Conditioning Association National Conference, Las Vegas, NV., 2013.
33. Stover, B, Szymanski, D, **Donahue, PT**. Effect of hip internal rotation training on range of motion and stride length in collegiate baseball pitchers. Presented at the National Strength and Conditioning Association National Conference, Las Vegas, NV., 2013

34. Szymanski, DJ, Carter, JG, Chandler, DR, **Donahue, PT**, Stover, JB, and Greenwood, M. Effect of 8 weeks of over-weighted implement training on bat velocity of novice college students. *Medicine Science Sports & Exercise*. 45(5): S419. 2013. Poster Presentation. ACSM Annual Meeting. Indianapolis, IN. May 31, 2013.

### **INVITED PRESENTATIONS**

**2018** – Positional Difference in Strength, Power, and Speed in Football Athletes, NSCA Mississippi State Clinic – Starkville, MS

### **RESEARCH COLLABORATIONS**

Department of Health Sciences & Kinesiology, Georgia Southern University  
Department of Kinesiology and Health Promotion, Troy University  
Department of Exercise Science, Lagrange College  
Department of Kinesiology, Louisiana Tech University  
University of Mississippi Center for Health and Sports Performance  
University of Mississippi Athletics Department  
Minnesota Twins Baseball Club

### **LABORATORY COMPETENCIES**

Exercise Prescription  
Muscular Strength Testing  
Electromyography  
Vicon Motion Capture Testing  
Force Plate Analysis  
Neurocom Equitest Balance Testing

### **CURRICULUM EXPERIENCE:**

#### **UNIVERSITY OF MISSISSIPPI**

##### **Undergraduate Courses - Primary Instructor**

ES 100 – Introduction to Exercise Science (80 – 100 students)  
ES 346 – Kinesiology (50 – 100 students)  
ES 402 – Exercise Leadership (20 – 50 students)  
ES 446 – Biomechanics of Human Movement (35 students)  
ES 391 – Trends and Topics (20 students)  
HP 191 – Personal and Community Health (35 – 80 students)  
HP 303 – Prevention and Care of Athletic Injuries (50 students)  
EL 151 – Weight Lifting  
El 147 – Tennis

## **LOUISIANA TECH UNIVERSITY**

### **Undergraduate Courses – Primary Instructor**

Kine 124 - Basketball

Kine 126 – Bowling

Kine 133 – Racquetball

Kine 136 – Indoor Cycling

Kine 144 – Weight Training

## **PROFESSIONAL AFFILIATIONS**

2008 – present National Strength and Conditioning Association

2009 – present Collegiate Strength and Conditioning Coaches Association

2017 – present American College of Sports Medicine

2013 – 2015 Professional Baseball Strength and Conditioning Coaches Society

## **CERTIFICATIONS:**

2012 – present Registered Strength and Conditioning Coach (RSCC)

2009 – present Certified Strength and Conditioning Specialist (CSCS)

2009 – present Strength and Conditioning Coach Certified (SCCC)

2009 – present American Red Cross: Cardiopulmonary Resuscitation and Emergency  
Cardiac Care Provider

## **SERVICE:**

2016 – present Ole Miss Health and Sport Performance Review Team

2016 – present Undergraduate Advising

2018 – present Graduate student supervisor of the Applied Biomechanics Lab

2018 – present Graduate student supervisor of the Center for Health and Sport  
Performance

## **Reviewer**

Journal of Trainology

International Journal of Exercise Science